SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

Journal and

TRANSACTIONS FOR 1888,

AND

GENERAL INDEX, 1861 TO 1888.

EDITED BY

G. A. PRYCE CUXSON,

SECRETARY.

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1889.

PREMIUMS FOR 1888.

At a meeting of the Society, held on February 4th, 1889, the following Premiums of Books were awarded, viz.:—

The President's Premium to:

HENRY FAIJA, M. Inst. C.E., for his paper on "The Effect of Sea Water on Portland Cement."

The Bessemer Premium to:

C. NICHOLSON LAILEY, for his paper on "The Acton Main Drainage Works."

A Society's Premium to each of the following gentlemen:

To WM. WORBY BEAUMONT, M. Inst. C.E., for his paper on "High Pressure Steam and Steam Engine Efficiency."

To W. SANTO CRIMP, Assoc. M. Inst. C.E., for his paper on "The Wimbledon Main Drainage and Sewage Disposal Works."

To H. ROSS HOOPER, for his paper on "The Practice of Foundry Work."

To WILLIAM LAWFORD, M. Inst. C.E., for his paper on "Light Railways."

To EDWARD PERRETT, Assoc. M. Inst. C.E., for his paper on "Filtration by Machinery."

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SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

COUNCIL AND OFFICERS FOR 1888.

Council.

President.—ARTHUR T. WALMISLEY.

Vice-Presidents. JONATHAN R. BAILLIE. HENRY ADAMS. ROBERT HARRIS.

CHRIS. ANDERSON.
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WILLIAM SCHÖNHEYDER.
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Past Presidents .. .. HENRY ROBINSON. PERRY FAIRFAX NURSEY. CHARLES GANDON. ARTHUR RIGG. JABEZ CHURCH. CHARLES HORSLEY.

Past President, and one of the Founders of the Society .. HENRY PALFREY STEPHENSON.

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OFFICES:

9, VICTORIA CHAMBERS, VICTORIA STREET, S.W.

PLACE OF MEETING:

THE TOWN HALL, WESTMINSTER.

1889.

TRANSACTIONS, &c.

February, 6th, 1888.

INAUGURAL ADDRESS

BY

ARTHUR THOMAS WALMISLEY,

PRESIDENT.

GENTLEMEN,

In addressing you for the first time as President of the Society of Engineers, I desire to thank you for the honour you have conferred upon me in electing me to the Chair.

This Society was originally started in the year 1854, as the Putney Club, formed out of the former students of the "College for Civil Engineers and of General Scientific and Practical Education," which had been established at Gordon House, Kentish Town, about the year 1839, but was removed to Putney a short time after this date. His Grace the Duke of Buccleuch, K.G., F.R.S., was the President of this College, and it was here that, among others who have made their mark in the world, Mr. Guilford L. Molesworth, M. Inst. C.E., of 'Molesworth's Pocket-Book' reputation, received his early professional training.

In 1858 the club assumed more the aspect of a scientific society, but with members of one class only. Rules were drawn up in January of that year, and the meetings of the Society removed to the Lower Hall of Exeter Hall, in the Strand. Premiums were awarded for the best papers, but it was not until 1861, that the papers read were printed in full, with illustrations and a brief account of the discussion. In June 1861, a conversazione was held at Exeter Hall, and repeated in 1862. In December 1861, the first Annual Dinner was held, and in March 1862, the first proposal to visit works was considered, resulting in arrangements being made for the Society to be shown over the Southern Outfall Main Drainage Works at Erith, in May 1862. So successful was this day's excursion, that in October 1862 the Northern Outfall Works were visited, and since then the Society has paid periodical visits to different works in progress during the summer vacation, which have

been reported in our 'Transactions,' and which have formed a prominent feature in the advantages offered by the Society to its members.

In 1858 we numbered 107 members; in 1859, 169 members; in 1860, 214 members; and in 1861, 233 members. In December 1862 the rules were altered, and it was decided that the Society should consist of three classes, namely, a class of Members, gentlemen above twenty-five years of age, who are or have been engaged professionally in engineering pursuits; a class of Associates, engineers who have not reached the age of twenty-five years, engineering pupils above eighteen years of age, and gentlemen of scientific attainments, whose pursuits constitute direct or collateral branches of engineering; and a class of Honorary Members, to be nominated by the Council, not to exceed twenty in number, who shall be gentlemen of distinguished attainments.

The rules of the Society were subsequently modified and improved at various times, and in December 1865 the annual subscription was fixed at two guineas for a resident member, one-and-a-half guineas for a non-resident member, and one guinea for both resident and non-resident associates. The entrance fee payable upon election was fixed the same in amount as the annual subscription for each class.

In December 1866 our numbers had increased to 310, and a paid Secretary was appointed. In November 1867, upon the Society's removal to Westminster, the great centre of engineering and parliamentary life, offices were taken at 6, Westminster Chambers. The present form of seal and certificate were then adopted, the latter simply stating that the individual holding the same was elected a Member or an Associate of the "Society of Engineers" upon the date named. In March 1868 the rules were again amended to enable the Society to work under "The Literary and Scientific Institutions Act" (17 & 18 Vict. cap. 112). Under this Act we obtain legal conveniences with respect to claims and actions of all kinds, quite as effectually as if we were an incorporated body, and also secure the following advantages:—(1) A provision for the ownership of the property of the Society by a governing body under that name. (2) The Society is empowered to sue and be sued in the name of an Officer to be determined by our own rules, without individual expense, and in a very simple way. (3) A judgment against the Society can only be enforced against the property of the Society, and thereby not only the Council but all the members obtain protection against personal responsibility. (4) In the event of our wishing to acquire land for a site to erect a building for the meetings or business of the Society, the grant can be made to

trustees, as we are not incorporated. (5) Under an incorporated Act (13 & 14 Vict. cap. 28) provision is made for the vesting of the property of the Society in new trustees if required. (6) The Council, as the governing body of the Society for the time being, have the full control of all its affairs and concerns, and thus acquire a convenient method of entering into contracts. (7) The Society is empowered to make bye-laws, to recover its subscriptions in a manner pointed out by the Act, and receives protection against the dishonest conduct of any member. (8) Lastly, and I trust the necessity for this may be very remote, the Act provides for the dissolution of the Society.

In 1883 the Society removed its place of meeting to the Town Hall, Westminster, and in December 1886 its Secretary's Office, Reading-Room, and Library to 9, Victoria Chambers.

During the past year, death has removed from us Sir Joseph Whitworth, a distinguished Honorary Member; Mr. Samuel Owens, the well-known manufacturer, of Whitefriars; Mr. William MacGeorge, Past President; and Mr. M. Ogle Tarbotton, M. Inst. C.E., Vice-President, who held the position of Consulting Engineer to the Gas and Waterworks of Nottingham, and whose decease was the result of nervous prostration produced by excessive brain-work.

The Society now numbers 236 members, 82 associates, and 64 foreign members and associates, making a total of 382 corporate members.

In a society much depends upon the united strength of individual efforts. To advance the interests of a society the Council need the support of all the members generally, and I feel sure I am expressing the wish of all my colleagues upon the Council, when I say that we will at all times be most ready to receive and consider any suggestion which any member may be willing to make as likely to prove conducive to the interests of the Society as a body. A policy of alienation among the members of a profession is both undignified and detrimental to the whole community, while all that tends to affiliation raises the value of the services which the profession can render to society in general. Man is insignificant by himself. He needs society, and much good is effected by the interchange of ideas which takes place at our meetings.

Our finances are in a satisfactory condition, and our work cannot be better described than by alluding to the meetings during any one of our complete sessions. To take the past session. Professor Robinson, M. Inst. C.E., in his very able Presidential Address delivered in February last, alluded to many important engineering projects, and dwelt at some length upon the essential conditions that had to be observed in preparing and

training a young man for the engineering profession. Engineering is becoming more exact and more scientific every day, and the requirements for success are annually extending. While civil and mechanical engineering form branches of study somewhat divergent from one another, they are intimately associated in practice. It is impossible to be a sound and successful civil engineer without a considerable acquaintance with the work of the mechanical branch of the profession. Hence in the papers which are read, the Council aim at providing both civil and mechanical engineering subjects.

In March a paper was read by Mr. Edmund Olander, Assoc. M. Inst. C.E., upon "Bridge Floors: their Design, Weight, and Cost." In this paper, which has been awarded the Bessemer premium for the year, the floorings noticed by the author were—(1) those of timber alone; (2) of timber on cross-girders; (3) of cross-girders with rail-bearers; and (4) the modern system of trough floors. Speaking of floors, I may mention that of the East and West India Dock Company's Goods Depôt, in the Commercial Road, Whitechapel, which was opened in September 1887, where the total floor-space, covering about eleven acres, is formed of 7-inch deals, placed on edge as close as they could be put together by cramps, and covered by $1\frac{1}{2}$-inch boarding, grooved and tongued. The building occupies a space 600 feet long by 200 feet wide, the flooring being supported by steel girders resting upon the walls.

Examples of the saving of headway effected by the use of trough-decking may be seen in the subways of the London, Tilbury, and Southend Railway Company's warehouse, where over 1000 tons of Lindsay's pattern have been used. Floors 9 inches deep, of 40-feet spans, were laid upon this system in the wards of the London Hospital, and floors 7 inches deep, 34-feet spans, at the National Liberal Club, Whitehall. The joints of the steel-troughing in Lindsay's pattern, which has been adopted by some of the great railway companies, are situated along the neutral axis of the trough, and are a weathered lap, so as to be protected against the lodgment of water. Messrs. Westwood & Baillie's corrugated flooring has been used both by the Indian and Cape Governments upon road and railway bridges, also upon the Holbeck Viaduct of the Great Northern Railway, and the Goods siding at Poplar, connected with the Midland Railway.

In the design of a railway bridge to be approved by the Board of Trade, where troughing is introduced, I am advised that if the flooring is properly constructed, the weight transmitted by the driving-wheels of an engine may be assumed to be spread over three troughs.

In the Charing Cross Bridge (S.E.R.) extension, designed by Mr. F. Brady, M. Inst. C.E., Engineer in Chief to the South Eastern Railway Company, the flooring is of 4-inch pitch pine planking, creosoted. In the Cannon Street Bridge (S.E.R.) extension, the flooring will be formed of wrought-iron plates, lap-jointed stiffened with angle- and tee-irons, riveted to longitudinal girders.

In April, the Shone Hydro-pneumatic Sewerage System was described by Mr. Edwin Ault. The plan adopted is to allow the sewage to flow from the houses, by gravitation to a given point, into ejectors. When the ejectors are full, compressed air is automatically admitted on the contents, which are expelled under pressure to a higher level, and by this means are driven to the point of distribution; thus, the difficulty of rising ground is overcome. The automatic action of the ejector, and of the house-sewer flushing-tank, as in use at Eastbourne, Henley-on-Thames, and the Houses of Parliament, were alluded to in this paper.

In May, a paper was read upon refrigerating machinery on board ship, by Mr. T. B. Lightfoot, M. Inst. C.E., in which he showed (1) how a perfect gas behaves during compression, cooling and expansion; (2) the effect of aqueous vapour mixed with such gas; (3) the application of these principles to the construction of cold-air machines.

In June, a paper upon the Renewal of the Arched Roof over the Departure Platform at King's Cross Terminus, G.N.R., was read by Mr. R. M. Bancroft, for which he has been awarded the President's premium. This roof, designed by Mr. R. Johnson, M. Inst. C.E., Engineer in Chief to the Great Northern Railway Company, was erected by Messrs. Handyside & Co., of Derby, Helliwell's glazing at the louvres being carried upon a specially constructed iron bar. The travelling stage was designed to provide a clear headway for the locomotives, so as not to interfere with the traffic, and to receive the thrust of the adjoining roof over the arrival platform during the progress of the new work.

Between June and the autumn followed our vacation visits, forming an important part of our sessional arrangements, and to which therefore I intend later on to draw your attention.

In October, a paper was read by Mr. R. J. Hutton, M.Inst.C.E., upon the Stability of Factory Chimneys, which elicited some valuable remarks upon the effects of wind pressure on curved and flat surfaces. This paper has been awarded one of the Society's premiums.

In November, Mr. Perry F. Nursey (Past President) gave us a most exhaustive paper upon Primary Batteries for illumi-

nating purposes. The leading characteristics of various special batteries were pointed out in a manner which would have entitled the Author to an award, if it were not for the existence of a rule that Members of Council are disqualified for the Society's premiums. The paper was well illustrated, both by diagrams, and by installations of several of the batteries, from which a number of glow-lamps were lighted. The opinion was expressed that so long as we must burn zinc or any other metal in a battery to produce the current, competition against secondary batteries would not be likely to succeed, but for mining purposes, where a portable self-contained electric lamp carrying its own battery could be provided, giving a reliable light during the whole period of a working shift, primary batteries would be capable of doing good service.

In December, a paper upon a New Formula for the Flow of Water through Pipes and open Channels, was read by Mr. Edgar C. Thrupp, which has received another of the Society's premiums.

The coating of the pipe has an influence upon the friction to be allowed for, and the flow is affected to no small extent by the form and distance apart of the joints.

In the Thirlmere Aqueduct of the Manchester Corporation Waterworks, which is now making good progress under the direction of Mr. G. H. Hill, M. Inst. C.E., the cast-iron pipes are formed, in places where the ground is fairly regular, of plain-ended cylinders, 12 feet long, laid end to end, and the joint is made by a collar covering both ends of the pipe, the space between the collars and the outside of the pipe being run up solid with lead, no yarn being used. The diameter being thus uniformly maintained, the pipe is free from the contingency which attaches to a socket. In other parts of the work where the surface is not so regular, two methods are adopted. (1) Where the ground is not liable to be affected by underground workings, the pipes are made with short sockets a little over 3 inches deep, which will also be run solid with lead. (2) Where it is possible that settlement might occur from workings underneath, the sockets are longer, and of the ordinary description.

Portland cement concrete has been largely used in works of construction, chiefly upon account of its strength, cheapness and adaptability. Its constituent, Portland cement, has been successfully employed in marine work for over a quarter of a century, but the limit of the amount of magnesia which the cement may contain is a subject of dispute. At our next meeting (March 5) a paper will be read by Mr. Henry Faija, M. Inst. C.E., upon the effect of sea-water on Portland cement, which I trust will elicit a profitable discussion.

Iron and Steel.

The manufacture of soft steels paved the way for the extended use of steel as a constructive material. When the new metal was first introduced it was not properly understood, and hence it was indiscriminately applied. The failure of the steel boiler-plates of the Russian Imperial yacht, *Livadia*, and the mysterious cracking of a number of steel angle-bars in the Royal Dockyard at Chatham, caused the whole family of steel to be regarded with suspicion for constructive purposes, but were due primarily to the absence of knowledge of the varying properties of different grades of steel, which led to error in selection. Then, again, there were defects of manufacture in the material, and sometimes unfair or mistaken manipulation, which causes, either singly or combined, contributed to failure. Nor is this to be wondered at, seeing the great variety of steels that are now produced. Starting from a commercially pure iron, carrying only 19 tons per square inch, we gradually reach mild steel, carrying from 28 to 30 tons per square inch, and progressing upwards, by stages, we at length find a hard steel, carrying from 58 to 60 tons per square inch. Between these extremes, various intermediate classes exist in the market, and hence it is not altogether surprising, that inappropriate selections have been occasionally made, which have led to a distrust of the material; but when the selection is judiciously made for the special purpose in view, and properly manipulated, satisfaction is obtained and security established.

The attainment of the knowledge required to effect this, does not fall to the lot of every constructive engineer. Hence, he is obliged to trust to the researches and experience of experts as to the percentage of carbon necessary to provide a given quality of steel; and there are leading firms in the steel trade who prefer to take the responsibility of supplying an appropriate metal to meet definite conditions, rather than have their reputation brought into question by the failure of steel of a certain character which has been supplied by them and applied to a given purpose, when the material should have been of quite a different kind. Of course, such a latitude would have to be covered by proper provisions as to guarantee of security or penalty in the event of failure; and it becomes the province of the engineer to supply the manufacturer with the amount of the unit-strain to which the material would be subjected in construction or when constructed.

Owing to the acquisition of a superior knowledge of the material, steel is steadily superseding both wrought and cast iron, and various improvements in plant have been devised for

its manufacture. Thus, within the last few years, methods of making steel upon known systems in small quantities have been introduced, the object being to enable the proprietors of small engineering works to produce their own steel when and as they want it, so as to obviate keeping a large stock on hand, or the alternative necessity of giving small orders, which are seldom promptly executed.

Castings of mild steel are also now made. A highly refractory material is necessary for the mould, yet one porous enough to allow of the escape of the imprisoned gases, and not capable of any chemical reaction with the fluid steel. A steel foundry requires more floor-space than an iron foundry. The moulds require to be perfectly free from moisture, which circumstance necessitates the use of boxes and stoving. Steel requires a much higher temperature to melt it than cast iron, and, as it solidifies and contracts immediately the temperature is reduced, it has to be fed direct from the head, on to the casting.

The manufacture of chains would appear to be the only stronghold of wrought iron with which steel cannot successfully compete, as, notwithstanding all the progress steel has made, it is as yet hardly reliable as regards its welding properties. Several inventions have been tried for making steel chains in experimental lengths. Cast-steel chains have been proposed and made abroad, notably on the systems of MM. David & Damoiseau, of Paris, and of MM. Joubert & Leger, of Lyons. In this country, at the Newburn Steel Works, Newcastle-on-Tyne, weldless steel chains, suitable for mooring purposes, shackles, eyes, hooks, and railway-couplings, as well as smaller chain outfits for ships, have for some little time past been made upon a somewhat similar system, invented by Mr. Penman. The links are each cast in chills separately, then placed in a connecting chill, so arranged that when the steel is poured in, the various pieces can immediately be disengaged, so as to prevent fracture by contraction during cooling. First two links are thus combined, then two sets of three, two sets of six, and so on; and this is now so satisfactorily done at the Newburn Steel Works, that it is seldom there are any wasters; but the chains so made, have not at present attained a commercial notoriety. Each chain is properly annealed to relax the tension caused by casting in rigid moulds, the annealing process inducing a molecular rearrangement which adds to the tensile strength and ductility of the material

Marine cranks of large size have been made without any hammering or work upon them, which pass the Board of Trade and Lloyd's requirements, the advantages claimed being that,

in whatever direction they are tested, the tenacity and ductility are satisfactory.

The manufacturers' charges for extras upon iron plates have become greatly modified in the face of the competition with steel. Twenty years ago Staffordshire iron-makers did not care to sell at a minimum price plates weighing more than 4 to 5 cwt., wider than 4 feet or longer than 15 feet. Within ten years afterwards, the weight allowed for ordinary prices was increased to 8 cwt., the width to 4 feet 6 inches, and the length to 20 feet. To-day one can obtain in fair assorted specifications, plates up to 10 cwt. each, up to 5 feet 6 inches in width, and up to 30 feet in length, at minimum prices. In the North of England, say, in the Cleveland district, where manufacturers lay out their mills for heavier weights than those required in bridge-work, plates for shipbuilding were sold at a minimum price, weighing 8 to 10 cwt. each, having a limited width of 4 feet 6 inches, or a length of 20 feet. Competition among the manufacturers for orders brought about an extension of these limits, and in 1878, plates of 13 cwt. each, length 23 feet, might be obtained without extra cost. To-day a weight of 15 cwt. is allowed, with a length limited to 30 feet, and a width limited to 5 feet, at ordinary prices. A plate of best Yorkshire iron $\frac{1}{4}$ inch thick is now charged at ordinary rate, if it does not weigh more than 3 cwt. and is not more than 3 feet 6 inches wide. These nominal limits are however sometimes exceeded.

Although for some years past the capacity of production in iron plates has been much in excess of the demand, and although the competition among iron-plate makers is annually increased, the limit of size and weight has apparently been reached at which iron plates can be economically produced.

Plates of great width demand expensive rolls. For boiler-making, iron plates are rolled by all the superior-class makers up to 6 feet 6 inches wide. With new boilers it is the custom for the maker to guarantee to the user, the work and capability of the boiler, and this stands good, subject to deterioration of ordinary wear and tear. The inspection of boilers under compulsory powers by Parliament is not likely to find favour among users, but the Act of Parliament may be useful where second-hand boilers are purchased by users of machinery not well versed in their working.

The falling value of steel plates during the last few years has had an influence upon the competitive prices for iron plates, and makers have now practically abandoned the struggle against steel. The liability to lamination, blisters, and heavy scale upon the surface, in thick iron plates, causes steel to be preferred. The thicker and heavier an iron plate the more

difficult is it to develop fibre and to get the iron to stand a high test. The chance of a flaw is greatly increased in a large plate, so that sometimes several plates may have to be made to get one perfectly sound, whereas the limits in size and weight of steel plates seem in a great measure to be merely confined to the weight of the ingot capable of being handily manipulated. An iron plate made up of blooms from puddled iron, or of iron piled together and hammered, is much more difficult to weld together than steel rolled out from an ingot of steel cast in a mould, as these ingots may be of any weight.

Steel plates are rolled up to 6 feet 6 inches wide and $1\frac{1}{2}$ inch thick. A plate $\frac{1}{16}$ inch thick ought not to exceed in area 28 square feet, 14 feet in length, or 4 feet in width. At ordinary prices the limit of width is 30 inches; the limit of weight for plates $\frac{3}{8}$ inch thick being 1500 lbs., the limit of weight for plates $\frac{1}{2}$ inch thick being 2000 lbs., and for any thickness above $\frac{1}{2}$ inch being 6000 lbs. The limit of length for plates $\frac{3}{8}$ inch thick is 40 feet, and the limit of length for plates $\frac{1}{2}$ inch thick 60 feet; for any thickness above $\frac{1}{2}$ inch the limit of length varies from 75 feet to 80 feet. The whole of these plates have rolled edges, that is, they are rolled to the specified width, and do not require to be sheared. Steel plates have been supplied by the Steel Company of Scotland, with sheared edges, 40 feet long by $36\frac{1}{2}$ inches wide, from $\frac{1}{2}$ inch to $\frac{5}{8}$ inch in thickness, for bridge purposes. The largest steel plates made for the floor girders at the Commercial Road Warehouse of the East and West India Dock Company are 47 feet $0\frac{1}{4}$ inch long by 19 inches wide by 1 inch thick, weighing 27 cwt., rolled in one piece.

Since our last visit, in September 1886, to the London Yard Engineering Works of Messrs. Westwood, Baillie & Co., the cantilevers which we saw being built for the Sukkur Bridge have been completed. These cantilevers were each 310 feet long, and are intended to carry a centre span of 200 feet, forming a bridge 820 feet between the centre of main pillars, or 790 feet span in the clear. The bridge, which has been designed by Sir A. M. Rendel, M. Inst. C.E., for a single line of railway, has been constructed of mild steel in plates and bars ranging from $1\frac{1}{4}$ inches to $\frac{5}{16}$ inch in thickness, riveted together with steel rivets. The roadway is to be covered with steel corrugated flooring. The long struts are rectangular in section, each corner of the rectangle consisting of a curved plate with angle-bars upon its edges, and the faces of the rectangle being occupied by transverse and diagonal bracing. Lengthwise the struts are curved upon all four faces, tapering from the middle towards the ends.

At the Forth Bridge, designed by Sir John Fowler and Mr. B. Baker, M.M. Inst. C.E., the horizontal member between the cantilevers, the sloping columns with their diagonal connections, also the bottom member and struts of the cantilevers, are formed in tubes of 12 feet and 8 feet diameter. The light cages surrounding the tubes, and the hydraulic and steam-power cranes used in the erection of the superstructure of the Forth Bridge have been so fully described in the professional journals that it is only necessary for me to remind you that this steel structure will have a span of 1700 feet from centre to centre of piers, the central girder measuring 350 feet between the ends of the cantilevers.

The main and cross girders now being erected for the widening of the Charing Cross Railway Bridge (S.E.R.) are of wrought iron, but the central platform girders, and the new main girders resting upon the old cylinders are made of steel, so as to reduce the additional weight brought upon the old cylinders to a minimum. In the widening of the Cannon Street Railway Bridge, the longitudinal girders carrying the lines will be formed of steel.

Contractor's Plant.

The experienced contractor is no mere employer of labour. He has to arrange his plant, carry out a specification, and often to take the entire responsibility of the work during its execution.

Contractor's plant is the handmaid of civil engineering. Steam overhead travellers for lifting and carrying about the yard are largely used in manufacturers' works, in which the longitudinal and transverse travelling motions can be worked in either direction without reversing the engines, and at the same time as the lifting or lowering motions are at work.

Portable cranes are now largely used upon works, in which the arrangements for altering the radius of the jib, lifting, revolving and travelling, can be all worked by one man without leaving the platform upon which the crane is mounted. These cranes are worked by steam and are very compact. The feed water for the boiler is carried in a tank below the footplate, and ample bunker space is provided for coal. The slewing and lifting motions can be operated simultaneously and in either direction. Where steel wire rope is introduced it is used for hauling purposes only. A wire rope requires a large diameter to be given to the winding drum, and a big pulley to check the spinning of the rope. Round a small barrel, a chain will work best, but a chain breaks without notice, whereas a rope will give indications of failure in the strands before it breaks.

In steam cranes it is considered that a horizontal arrange-

ment of cylinders and gearing give a better distribution of strains and a lower centre of gravity.

At the Tilbury Docks, besides various other plant, Messrs. Kirk & Randall, the original contractors during the early portion of the work, had some two-ton steam travelling cranes made and designed by Messrs. Jessop & Co., of Leicester. These cranes are of the horizontal pattern, the weight of the engines being used at the back to help counterbalance the load. The arrangements are such that there is as much weight upon the back of the roller-path, when no lifting is being done, as there is upon the front of it when the load is on. All the weight is carried by the centre pin and two back rollers when empty, and by the centre pin and two front rollers when loaded. The chief peculiarity is the application to the slewing gear, of Grafton's patent geared ring. The top side of this ring forms the roller-path. It is not fixed to the base in any way, but is kept from turning round simply by the weight of the crane resting upon it. Should the crane-driver attempt to rotate the crane too suddenly, the ring merely slips round upon the crane bed; and so successful is this arrangement in practice, that whereas in the ordinary cranes broken stearing gear is a continual source of trouble, it is seldom a tooth breaks in the Grafton crane. At our visits to these extensive dockworks in June 1885, and again in 1886, during their completion by Messrs. Lucas & Aird, one could not fail to be struck with the enormous quantity of plant employed.

Cranes were employed for extending the masonry superstructure of the piers at the mouth of the river Tyne, by means of which the foundation blocks were placed 30 feet below low water spring tides, without the use of staging. These cranes, designed by Mr. P. J. Messent, M. Inst. C.E., the Engineer to the River Tyne Improvement Commissioners, are capable of setting blocks upwards of 40 tons weight at a distance of 75 feet beyond the supporting wheels, or in a radius of 92 feet from the centre pivot.

In the construction of the North Wall, Dublin, designed by Mr. B. B. Stoney, M. Inst. C.E., concrete blocks 29 feet high by 21 feet 4 inches broad at the base, and 11 feet 6 inches long, weighing 350 tons, were built on land, and three months after their completion they were lifted by means of the iron suspending bars which passed through each block, assisted by powerful floating shears, and lowered into position. The foundation to receive them was previously excavated and levelled with the aid of a diving-bell weighing 80 tons, cofferdams being thus dispensed with, and the superstructure above these blocks was carried up in the usual way by tidal work.

For the Las Palmas Harbour Works, belonging to the

Spanish Government, a depositor was used, designed by Mr. C. J. Appleby, M. Inst. C.E., which rotates 60 feet radius and travels by its own steam, carrying the load in or out. This depositor was constructed to be capable of laying 12 concrete blocks of 40 tons a-day, but as a matter of fact, it is reported to have laid 21 blocks in one day when forming the harbour works.

A novel type of crane has recently been constructed by Messrs. Ransome & Rapier, of Ipswich, called the "All-round Titan," having a working radius of about 70 feet round a complete circle, and weighing 320 tons. The whole machine is carried on springs and mounted upon a carriage, high enough to allow trucks to run beneath the crane. It travels upon special rails 21 feet gauge, and is to be used upon the Warrnambool Harbour Works in Victoria.

Mr. T. A. Walker has a variety of excavators at work upon the Manchester Ship Canal. The smallest in use are grab-cranes made by Messrs. Priestman, of Hull, which are working with the grab proper and also with an arrangement fitted by Messrs. Whitaker, of Horsforth, near Leeds, which works a bucket like a steam navvy, the contents of the bucket being one cubic yard. The fact that when not required for dredging or excavating they can be used as ordinary lifting cranes makes them valuable plant to a contractor. The chain allows the bucket to be worked at a depth of 25 feet or more below water. Mr. Walker has also several of Messrs. Ruston & Proctor's steam navvies, each weighing 45 tons, having a range of 45 feet in width, with a bucket containing 1½ cubic yards, and capable of raising about 1000 tons of earthwork a-day. The largest steam navvies yet made are, I believe, those used by Mr. Easton Gibb, Assoc. M. Inst. C.E., in the excavation of the shale upon the site of the Upper Barden Reservoir, belonging to the Bradford Corporation, under the direction of Mr. A. R. Binnie, M. Inst. C.E. These weighed 60 tons and 70 tons respectively, and were specially made for this heavy work at Barden by Messrs. Andrew Barclay & Son, of Kilmarnock. The gearing throughout was of cast steel, except the largest driving-wheel, which was of cast iron. The bucket, which had a capacity of 1½ cubic yards, was controlled by an engine on the jib of 6 horse-power, which was found to be of great advantage, enabling the driver to pull back or press into the face as required. The winding engine was 20 horse-power. A fair day's work of ten hours was reckoned to amount to an excavation of 500 cubic yards of strong shale weighing about 1000 tons. Upon the Manchester Ship Canal, Mr. Walker is working a number of excavating buckets fitted to five-, seven-, and ten-ton cranes; also a land dredger to lift 2500 tons per day, working as an

ordinary ladder dredger; and another of a similar pattern, to raise 3000 tons per day, is now being made in France for these works.

Dredgers to leave a required depth of water after dredging have been made by various firms, such as Messrs. Rennie, Messrs. Hunter & English, Messrs. Priestman, and others. They act as a floating planing-machine. The construction of the Tilbury Docks was seen at our visit in June 1886 to have been greatly facilitated by the use of a dredger drawing 45 feet of water, designed and made by Messrs. Hunter & English, of Bow, which delivered 1400 tons in five hours of actual work. Mr. S. Williams has a dredger now at work near the northern outfall of the Metropolitan Main Drainage at Barking, made by the same firm, which draws or makes 56 feet of water. The position is regulated by six chains—four quarter, and two fore and aft chains. In the upper reaches of the river Thames one is at work by the Thames Conservancy with non-condensing horizontal engines, the dredger making 12 feet of water. The buckets have a capacity of 6 cubic feet. The top tumbler turns eight revolutions a minute, giving a delivery of 16 buckets. Another dredger, making 15 feet of water, capable of delivering 70 to 80 tons per hour into barges, has been engaged in bringing up chalk-flint pieces weighing one to two cwt. each.

The method of lowering caissons by means of screws, adopted by Messrs. Lucas & Aird in the foundation of the piers for the new railway bridge, designed by Mr. J. Wolfe Barry, M. Inst. C.E., which carries the London, Chatham and Dover Railway across the river Thames, is worthy of notice. The wrought-iron caissons in which the foundations were laid were 32 feet by 30 feet in plan, and 21 feet deep. They were built upon a stage, and suspended by rods 2 to $2\frac{1}{2}$ inches diameter, having screw ends at the top 6 feet long, and fitted with nuts $3\frac{3}{4}$ inches deep, working upon cast-iron washers 12 inches outside diameter, $2\frac{1}{2}$ inches deep, with planed surfaces, supported by a beam 6 feet above Trinity high-water. The rods were in 5-feet lengths, but the top rods including the screw end were 9 feet long. The lengths were connected by link heads with a cottered joint at the end, and gave a steadier action than chain tackle. Three caissons were employed in each ordinary pier. They were carried by four of these suspension rods placed one at each corner of the caisson, the spanners which turned the nuts for lowering them being caused to move simultaneously by a rope connected with a travelling crane. The visible masonry piers were erected upon the concrete and brickwork built in the wrought-iron caissons.

A similar method of building the piers without the use of cofferdams is being adopted at the Tower Bridge by Mr. John Jackson, the contractor. The same size rods ($2\frac{1}{2}$ inches diameter) are employed, but with larger screws ($3\frac{1}{2}$ inches diameter). In this bridge, which the engineer, Mr. J. Wolfe Barry, has given the Society permission to visit next summer, there are two piers placed so as to provide a central span of about 200 feet, and the central platform will be accommodated with lifting apparatus for opening, when required by the shipping. Twelve wrought-iron caissons are employed in each pier, the permanent portions of which are sunk entirely below the bed of the river, the upper portion, 38 feet high, being removed after the piers are built. The eight central caissons (four upon each side) are 28 feet square in plan, and the angle ones forming the cutwaters upon the up and down river sides are 33 feet 8 inches by 35 feet. The caissons are placed with their outer sides 2 feet apart in line, into which space chock-piles are driven, forming a joint so tight that no continuous pumping is required to keep the inside dry when once the caissons are sunk. The inner sides of each of the iron caissons are removed after cutting out the rivets connecting them at the angles, so as to make a continuous dam, within which the pier is built. The clay at the bottom of the caissons is undercut about 5 feet deep upon the outer sides of the piers in order to obtain a sound footing, and Portland cement concrete, 6 to 1, 24 feet deep, is inserted to form the foundation upon which the upper portions of the piers stand. The central portion of the piers is then built and bonded in with the work previously executed.

At our visit to Messrs. Aveling & Porter's works, last June, at Rochester, we saw various details of traction engines and steam road-rollers in course of production, the cranks being formed in two heats from straight shafting. We also saw an ingenious machine drilling, and putting in at one run, the threads in the fire-boxes and boilers for the stays. The holes for the brasses in the journals were also being bored on both sides of the side-frames at the same time, by a special machine, so as to be in perfect truth.

The distribution over iron manufacturers' works of Tweddell's hydraulic riveters, radial drilling-machines, shearing-machines, and cold-iron saws is now very general. Hydraulic machinery is also used for forming cranked ends by pressure within blocks, which give the pattern, and for making stiffeners for girders, and plates are flattened by rolls without hammering, so as to distress the iron as little as possible. The steel circular saws cut cold bars, angles, tees, or channel irons across upon any line, leaving a smooth face. These are made 20 inches to 36 inches

diameter, working like a circular slotting machine, controlled by a worm-wheel action, and forming a series of tools acting one after the other. A 30-inch machine is used to cut a rolled joist 8 inches deep.

Emery wheels are sometimes used for finishing off the ends of small bars, but when the edges of a large assemblage of bars have to be dealt with, they must be planed.

At our visit, in July last, to the Works of Messrs. Maudslay, Son & Field, in the Westminster Bridge Road, we saw the model of the first screwing-machine ever made, which screwing-machine was constructed in 1800, and remained in the uninterrupted service of the firm for eighty years. In their shops there is a cylinder-boring machine, standing 17 feet high, capable of boring a 140-inch diameter by 12 feet deep. It is driven by its own engine, and was erected in 1881. Another tool we noticed in these works was a planing and slotting machine, 25 feet high, and occupying an area of 30 feet by 25 feet. It planes a surface 25 feet by 20 feet, and slots 20 feet high. The weight of this machine is over 100 tons, without its driving engine. The firm also showed us a large screwing-machine 18 feet long by 3 feet 5 inches, and screwing a 6-inch diameter in steel, at one cut. The machine gears up with change wheels, thus ensuring accuracy with speed. It was observed that Messrs. Maudslay find it to their advantage to provide independent engines to all their large tools.

To refer to other works that I am familiar with, Messrs. Handyside & Co., at their extensive works in Derby, have fixed steam riveters, together with hydraulic plant for complicated and heavy work, and something like 100 spindles for drilling. Messrs. M. T. Shaw & Co. have at their works at Millwall a travelling roof running upon a double gantry, 500 feet long, under which men can work in wet weather, and over which a travelling crane is fixed, commanding the whole length of the yard. At these works they have also in one shop an automatic machine for punching a series of holes at a given pitch without the labour of marking more than the first hole with a centre punch. A template is fixed under a table, with bolt-heads projecting at a set pitch. These are worked forward to set the plate in the proper position for being punched, by allowing the pin or body of the bolt to move a worm-wheel, in which the worm only extends over a part of the circumference. During the time required for punching, the template is prevented from travelling forward by the pin remaining in a parallel groove formed upon the wheel itself. Messrs. S. Cutler & Sons, of Millwall, have a machine capable of punching 78 holes $\frac{7}{16}$-inch diameter through $\frac{1}{4}$-inch plate at one stroke.

A very useful illuminant for contractors' yards and works, known as the Lucigen light, is coming extensively into use. It is produced by the combustion of the lowest residuum of petroleum oil through a jet, by which it is combined with a current of compressed air. This can be readily provided wherever a steam engine is available. The complete apparatus is very simple, and the cost much less than coal gas. Its use enables workmen to work by night as easily as by day, and it has been adopted for this purpose at many works upon the river Thames and other places.

Steam and Electric Traction.

Progress is sometimes aided, as we saw in our visit to the Ealing works of the Grand Junction Waterworks Company, by the construction of narrow-gauge tramways for the conveyance of material, which can be laid down by arrangement with the landowners, where there are no fences to interfere with; or where fences must be crossed, the least objectionable method is to carry the line of tramway through the gates. About half an acre of ground is required per mile run of tramway.

Light railways have been adopted a great deal upon engineering works, as well as upon public roads, both in this country and abroad. The increased demand for cheap and rapid transit has led to the adoption of various motors to meet the different local conditions; and the vast amount of horseflesh annually expended in hauling street cars along steep roads is being gradually reduced by the introduction of mechanical power. Light steam locomotives for tramways have been constructed to run at a speed of 6 miles an hour up inclines 1 in 25, drawing loads of 13 to 44 tons, exclusive of their own weight, and capable of taking proportionate loads up other gradients upon ordinary roads. The weight of the engines varies considerably, according to the requirements of the district, ranging from about 7½ tons to 15 tons. The valve motion is arranged so as to permit of all working parts being encased and protected from mud and dust.

Tramway engines can be made to suit any gauge. In narrow and confined thoroughfares it has been deemed necessary to adopt a narrow gauge. At Leeds, the steam tramways have a gauge of 4 feet 9¼ inches, and the tramcars measure a width of 6 feet 9 inches over all. On the Metropolitan lines the gauge is about 4 feet 7½ inches, and the tramcars measure 6 feet 6 inches over all. On the Greenwich and Plumstead line the gauge is 3 feet 4½ inches, and the tramcars are 5 feet 9 inches over all. From this it appears that the width of a tramcar to accommo-

date passengers sitting opposite to one another, cannot be reduced to such an extent as the gauge, and hence I think it advisable to adopt a minimum gauge of 4 feet, as more room is allowed for the driver of the engine, and the machinery is more accessible than when the engine is made of less width. Curves of 60 feet radius can be traversed with facility by these engines, and at a slow rate of speed the wheel base will admit of a 30 feet radius.

Steam tramway engines to work both ways have been made by various firms, notably by Messrs. Kitson & Co., of Leeds, and Messrs. Merryweather, of Greenwich, for numerous tramway companies both at home and abroad. The advantages of steam locomotion over horse traction are, reduced working expenses combined with increased power and applicability to lines with a fluctuating traffic, engines when not in use only needing the cost of a place of safety and shelter.

The first run with an electric tramcar in this country took place at Leytonstone, upon the North Metropolitan Tramways Company's system early in 1882, and since then the discussion and claims of inventors have been chiefly upon the position of the motor and the means adopted to communicate the motion to the road wheels. With a motor placed under the flooring of the car, motion has been transmitted to the wheels by bevel gearing, the spindle of the armature being prolonged to carry a pinion which gears into a circular fixed rack. Belt gearing is found to be a source of anxiety to the driver unless examined after every run. Chains wear out of pitch. In spur gearing there is a difficulty of providing for the play of the springs while at the same time keeping the tooth wheels accurately in gear. When the motor is fixed to the body of the car the advantage of the play of the springs is gained without the motion affecting the gearing. Arrangements have been made with the Metropolitan Railway Company for the Electric Traction Company to run an experimental train upon a section of their outer circle to be propelled by an electric locomotive of the same power as the present steam locomotives. The weight of an electric engine is less than the ordinary locomotive, so that the wear and tear of the line becomes reduced by its use, and avoidance of the intolerable rumbling noise and gaseous exhalations is among the advantages offered.

Since a cable tramway was first run in San Francisco, in 1873, the system has been introduced into many parts of the world where steep roads have to be dealt with. In England the system was first introduced into London upon the Highgate line, which has been running for nearly four years under the supervision of our Member of Council, Mr. W. Newby Colam,

Assoc. M. Inst. C.E., who favoured us with a paper upon Cable Tramways in May 1885. In Edinburgh about three miles of line have lately been constructed, in which by the skill of Mr. Colam, many entirely new mechanical features have been introduced into the design. Notwithstanding that two sharp right-angled curves have had to be dealt with, this line with duplicate power and driving gear, has been constructed and completely equipped to run cars at five minutes' interval, for about 8600*l.* per mile of single way. Another important line of cable tramway, from the designs of Mr. E. Pritchard, M. Inst. C.E., and Mr. Joseph Kincaid, M. Inst. C.E., M.A., has been constructed in Birmingham. The total length, from Colmore Row to Handsworth, will be 15,600 feet, of which 6600 feet of cable, extending from Colmore Row to Hockley Winding Station, has been threaded and run, and this length will soon be publicly opened for traffic.

It is contemplated that a considerable traffic will travel by the City of London and Southwark Subway, which is being constructed from the designs of Mr. J. H. Greathead, M. Inst. C.E., and in which the cable system, propelled by stationary engines, is proposed to be used. In our visit to these works, last July, we saw that a steel shield, overlapping (like the cap of a telescope) the forward end of the iron tunnel, was driven forward by hydraulic power, as the clay is excavated before it, and the flanged segments of the iron lining, 1¼ inches thick, are built up inside, and under cover of the shield, into successive rings about 1 foot 7 inches long, to form a subway of 10 feet inside diameter. As the shield was moved forward, the annular space outside the iron tunnel left by the advance of the overlapping steel plate of the shield was filled up with hydraulic cement, ejected from a vessel inside the tunnel by air-pressure. Air-compressors, driven by a small engine, and working up to a pressure of 40 pounds per square inch, were used at each shaft for this "grouting." Thus, all chance of settlement was avoided, and the iron tunnel was protected upon the outside by an impervious coating.

At the Tower Subway, the diameter was made 7 feet 2 inches inside, and a specially-constructed, commodious omnibus was run through when it was first opened. In the City and Southwark Subway, the up and the down lines are arranged in independent tunnels, both of which will be perfectly free from the products of combustion, due to the propelling power being placed in shafts adjoining the subways. The first tunnel has now been driven completely through between King William Street and Great Dover Street, and is being driven between the latter station and the Elephant and Castle. The second

tunnel is completed nearly to the same extent. The extension to Stockwell is in progress, and the whole line is expected to be completed in about twelve months.

Marine Engines.

Every year an increasing number of our population depend for their daily bread on grain conveyed by ships from abroad. Although steam has largely superseded sails, there are still no fewer than 18,000 sailing ships registered in Great Britain, not including the colonies, and, as in steam, so in sail, the tendency is persistently towards larger vessels. The *Palgrave* sailing ship is known to have a registered tonnage of over 3000 tons, and these limits are likely to be exceeded. Our mercantile marine is much the largest in the world, and the rate of steaming is as a rule from 13½ to 14 knots per hour. Some vessels steam 16 knots per hour.

The greatly increased speed which has lately been attained by the highest class of ocean-going steamers has been rendered possible commercially by the adoption of triple and quadruple expansion engines. These improved methods of taking advantage of the expansive power of steam have allowed higher pressures to be adopted, coupled with a correspondingly higher grade of expansion, because the division of the total expansion among three or four cylinders so reduces the range of temperature in each, as to considerably lessen the thermal loss, and (especially when more than two cranks are introduced) causes the turning movement throughout the circle of revolution to be more uniform. Not only is a better balancing of the moving parts permitted by this arrangement, but a greater number of revolutions per minute is obtained, without sacrificing steadiness. Greater power is capable of being realised per unit of weight of engines, while the economy of fuel attained by the triple and quadruple types of engines over the ordinary compound type, allows a larger power necessary for the increased speed to be provided, with about the same expenditure of coal, and for the same stowage capacity as a compound type of engine. This reserves to the paying cargo capacity of the vessel an unencroached space, while the economy of fuel attained by these developments, enables profits to be earned at a lower rate of freight than with the use of older vessels. Other advantages may be assigned to the later type of engine, such as a greater immunity from complete failure at sea, due to a breakdown in either cylinder, as the remaining two can be made available. The great weight of engines used in propelling large vessels is now also considerably reduced by

the substitution of steel castings instead of cast iron, and steel hollow forgings instead of solid wrought iron for many parts of the machinery. The displacement of the vessels is further greatly reduced by the use of steel plates and framework in their construction.

Coaling Stations.

The necessity of providing a proper number of coaling stations, and of protecting them, is a question both of commercial and naval importance. In olden times the sailor desired nothing but a favouring wind to carry the British flag all round the world. In later days the wooden ships could be repaired by the ship carpenters, but our modern iron and steel ships need docks where they can be examined, repaired, and replenished. To show the value of the application of suitable machinery at a coaling station, I may mention that Messrs. Appleby Brothers inform me, they have made 20 tons Gantry cranes, which have loaded 3600 tons of coals in 54 working hours at a cost of a farthing a ton.

Hydraulic Machinery.

The first Dock Company to fit up their docks upon an extensive scale with hydraulic movable cranes was the Millwall Dock Company, under the advice of one of our members, Mr. F. E. Duckham, M. Inst. C.E. These cranes are arranged to run on railway metals, so as to be movable at pleasure to any part of the dock. On a hydraulic main, connections are made at every 9 feet, so that instead of incurring the expense and loss of time in moving the ship to suit the crane, as was necessary when the crane was fixed, the cranes can be moved and concentrated where required, and as many as are wanted to fit the positions of the hatchways of the ship set to work. Crane-stages carried by piles are also introduced at the Millwall Docks, placed at a distance of a ship's width off the quay and parallel to it, so that when the ship is between the stage and the shore, a double set of cranes may be employed, viz. the shore cranes, discharging on to the quay, and the stage or dolphin cranes, into barges. By this plan eight cranes can be set to work simultaneously, with as many loads on to the ship. The arrangement of turntables is also unique. To unload 20 ton grain-bins at the Millwall Docks, into barges, they often require to be placed on a line of metal 2 feet 6 inches above, and at right angles with the main line, for which an ordinary hydraulic lift is adopted containing a pair of spiral grooves upon the outside of the lift cylinder. The platform

has two wheels fitting in this, so that the table and bin are turned one quarter-circle in the process of elevation.

The rapid discharge of cargo-carrying steamers required by shipowners has led to the adoption of hydraulic appliances at other docks. The supply of water pressure to the cranes can be obtained by means of telescopic or flexible pipes, or by pipes in short lengths with universal joints, called "walking pipes," the former giving the best results, as changes in the direction of the flow of water are less abruptly affected. The buildings to contain the engines, boilers, and accumulators should be as central as possible.

An archway type of movable hydraulic crane is constructed, which allows engines and trucks to run underneath between its supports. By this means the trucks get close to the quay-side, and the swing of the crane to load and unload such trucks to the vessel is reduced.

In October of last year the steamship *Cleveland*, 3110 tons burden, with full general cargo from Rotterdam, was completely discharged in seventeen hours at the Victoria Wharf, Cardiff, which contains four hydraulic cranes of a compound or double-chain type, designed by Mr. C. R. Parkes, Assoc. M. Inst. C.E., of the East Ferry Road Engineering Works, each of which cranes is fitted with two or three independent cylinders, and rams of different lifting power, to suit the weights of the goods lifted. The jib also is fitted with two or three jib-head sheaves, all under the control of one man, and capable of lifting two or more packages at the same time.

The increased use of lifts in the Metropolis has tended to a rapid extension of the application of hydraulic power. So far back as 1860 an Act was obtained by a company called the London Hydraulic Power Company, with authority to use water from the water companies' mains under the Waterworks Clauses Act, 1847, as well as from the river Thames. In 1871 another Act was obtained by the Wharves and Warehouses Steam Power and Hydraulic Pressure Company, to which Messrs. Burrell and Valpy, MM. Inst. C.E., acted as engineers. The basis of this Act was to work the wharves situated between Blackfriars Bridge and the Tower, over an area of 600 yards in width, measured from the centre of the river Thames upon both sides of the river, with power to draw water from the river not exceeding 1,000,000 gallons a day. In 1872 the Hull Hydraulic Power Company's Act was obtained, and these works were carried out by our Past President, Professor Robinson.

In the same year the Liverpool Hydraulic Power Company's Act was first obtained. It has since been renewed, and about ten miles of mains were laid last year. In 1884 another Act

for the Metropolis was passed, under the title, "The London Hydraulic Power Company's Act," with a limit of area extending from the East and West India Docks to the public parks at the West End, and embracing the whole of the City and Southwark. The water is taken from the river Thames and filtered before it reaches the main engine at the pumping station. Messrs. Ellington and Woodall, MM. Inst. C.E., are the engineers to the company, and about twenty-five miles of mains are now laid in the public streets. The service pipes are paid for by the consumer. The reservoir of power consists of accumulators loaded to a nominal pressure of 700 lbs. per square inch. All apparatus subjected to the pressure from the mains, is tested to 2500 lbs. per square inch, and a relief valve loaded to 800 lbs. per square inch is fixed upon all service pipes exceeding 1 inch internal diameter. The exhaust water in the return main is first measured by meter and then led to a drain.

Compressed Air System.

The works for the supply of a compressed air power in Birmingham, which have been executed under the engineering direction of Professor Robinson, with Mr. John Sturgeon, are now approaching completion. The object of the project is to concentrate compressed air at a central station and to distribute it through mains to manufacturers' works, where it can be used instead of steam as a motive power for driving their machinery. From experiments that were made for the purpose of obtaining the support of the Corporation of Birmingham, it appears that in Birmingham the average annual cost per indicated horse-power of steam engines up to 25 nominal horse-power exceeds 17*l.*, while the company expect to be able to supply over a wide area an equivalent amount of power in compressed air at 5*d.* per 1000 cubic feet at the average rate of 13*l.* per indicated horse-power per annum. The scheme will possess the further advantage that the motive power is never wasted. It is obtained at the time it is wanted, and at a cost to the consumer proportional to the power absorbed.

Tramcars propelled by the agency of compressed air have also been successfully run.

Municipal Work and Private Enterprise.

A great many large and important undertakings connected with cities and towns previously carried out by private enterprise are now gradually drifting into municipal channels, to which movement a considerable stimulus has been given in the power

granted by Parliament for the authorities to obtain loans from the Local Government Board for permanent works, upon the security of the rates, to be repaid over a period not exceeding sixty years. The amount raised must not at any time exceed (including all outstanding debts) the assessable value of the district for two years, and where it exceeds one year the Local Government Board institute an inquiry conducted by one of their inspectors.

A proper system of sewerage is primarily of sanitary importance. Municipal authorities work under the Public Health Act, 1875, an Act which includes the essential conditions prescribed by all previous Acts. It excepts the Metropolis, which is provided for by the Metropolis Local Management Act, 1855. In this Act the vestries are constituted the sanitary authorities for the Metropolis.

A good system of water supply is also an absolute necessity of life. Waterworks are now generally taken up in the country by municipal or local sanitary authorities. During the session of last year, Parliament decided, upon grounds of public policy, that the water supply of Sheffield should be transferred to the Corporation. Under municipal management water supply is provided at the cost of those benefiting by it. The inhabitants do not imagine their water supply can be better managed by a corporation than by a private company, but they generally get the water cheaper.

The freedom from tolls of piers at seaside places seems quite as reasonable a municipal object as the opening of public parks. The control of gasworks is not a sanitary question, and may either be acquired by a municipal authority as a commercial enterprise, or may be the property of those dwelling perhaps miles from it. In the case of a tramway managed by a corporation the roads are under one control.

Electric lighting has created considerable excitement in the past as a speculation, but whatever commercial progress it may make in the future, it has not at present attained the success which was expected by its originators. It has been chiefly adopted at railway stations, also for lighting individual buildings and contract works in course of progress.

Notice of application to Parliament in the ensuing Session has been given for a provisional order to authorise a company, called the South Metropolitan Electric Supply Company, Limited, to store and supply electricity for public and private purposes throughout the centre of London upon both sides of the river Thames.

One reason why gas has not been superseded for the lighting of boroughs and towns is doubtless due to the want of security

given to private enterprise by the Electric Lighting Act of 1882, which, like the Tramways Act of 1870, only secures concessions to private companies for a term of twenty-one years, at the end of which period corporations or local authorities can purchase the interests of the undertaking at a fair valuation of the buildings, land acquired, works, and materials. In 1878 and 1879 numerous experiments were made in the streets of London, as well as in provincial towns, to ascertain the cost of the electric light, and to test its efficiency as compared with gas. The electric lighting of districts on the constant supply or accumulator system is a safe, reliable, and economical means of distribution, and since its first introduction considerable attention has been paid to the development of automatic apparatus.

The supply from a central station works well, when provision is made against stoppage, which may arise either (1) by the circuit, which is conveyed through insulated cables over the tops of the houses, becoming interrupted by various causes, and (2) by the breaking of the driving-belt or the connecting gear to the engine, causing the action of the dynamos to fail. To obviate the inconvenience which might arise from such a disaster, Mr. Killingworth Hedges, M. Inst. C.E., consulting electrical engineer, recommends the placing of a set of secondary batteries in each house, these batteries remaining the property of the local electric light company, and kept under their control, probably in the cellars of the house, as a reserve in the event of a breakdown, or for use at night when only a few lights may be required.

Geology and Engineering.

The proceedings of the International Geological Congress, which is to be held in London this year from September 17th to 22nd (both inclusive), will be of interest to engineers. It is now about one hundred years ago since Hutton, a scientific gentleman of that day, laid the basis of our present experience by teaching that the geological formations were relics of other formations, and were the result of natural causes produced by similar forces to those now at work. At that time the title of Civil Engineer in Great Britain was only just beginning to be known. The help that engineers and geologists have since given one another has been mutual. The open trenches, tunnels, and well-borings, which have been executed by engineers, have given geologists information for which they have repaid us by their careful classification, deductions, and comparisons.

Rainfall and Water Supply.

The importance attached to the financial results of the dry weather of last year, and its connection with water supply in many districts, suggests that I should allude to the question of rainfall in this country, and the largest amount that can be depended upon for the water supply of towns. The mean average annual rainfall generally varies in England from about 20 inches in some of our eastern counties, up to about 150 inches upon the hills of Cumberland, but the intervals of dry seasons give the true standard tests of the volume which the waterworks engineer in designing gravitation works should depend upon.

From observations recorded by Mr. G. J. Symons, F.R.S. (the best authority in this country upon the subject), at more than 2000 stations in Great Britain and Ireland over a long series of years, it appears that (1) the wettest year has a rainfall nearly half as much again as the mean; (2) the driest year has usually one-third less than the mean, but at three stations last year, situated in Manchester (Lancashire), Huddersfield (Yorkshire) and Seaforde (Down), the deficiency has amounted respectively to 40, 39, and 41 per cent. of the mean; (3) the driest two consecutive years are generally taken to average one-quarter less than the mean; and (4) the average of the three driest consecutive years, upon which calculations for supply are usually based, is often taken as one-sixth less than the mean; but from a full investigation at 45 stations in Great Britain, made by Mr. Symons during a period of 43 years (1840 to 1882 both inclusive), the average of the three driest consecutive years in this country works out 79 per cent. of the mean, so that a deduction of one-fifth instead of one-sixth would be more accurate. It is worthy of note that (5) the extremes both of wetness and dryness are less pronounced at wet stations than at dry ones. The amount that can be collected is governed by various local causes such as the direction and character of the prevailing winds, the level of the ground above the sea, its proximity to hills, and the general features of the district. The amount lost by evaporation and absorption must also be allowed for, this amount being largest where the rainfall is small and the area flat. It varies from 10 up to 18 inches in the British Isles.

It is difficult to define what is meant by drought in an engineering sense. If by a partial drought is meant a period of twenty-eight or more days with not more than $\frac{1}{4}$ inch of rain, and by an absolute drought is meant a period of fourteen or more days without any rain, then the really remarkable feature of the dry weather of last summer was the length of the absolute

drought. In London during 1887 the fall has not been unprecedentedly small, for during the long-continued dry weather (over seven months) extending from February to August, an amount of 10·12 inches fell, a value equal to 67 per cent. of the average during the same period 1870–79, as against 52 per cent. recorded in 1874 (see Table, p. 28). There was an absolute drought, during which no rain fell, for 25 days, from June 9 to July 3; and there was a partial drought of 37 days, with only 0·16 inch of rain, between June 4 and July 10.

At Boston the absolute drought lasted 31 days, and the partial drought 36 days. At Strathfield Turgiss there was an absolute drought in June and the early days of July for 15 days, and a partial drought for 50 days. At Culford during the month of June and the beginning of July the absolute drought lasted 30 days, and there was a partial drought during 43 days. Periods of 14 successive days without any rain at Camden Square are also recorded in the months of February, April, and August. At Hull the duration of the absolute drought was 30 days and the partial drought 43 days. At North Shields the absolute drought did not last 14 days, but there was a partial drought for 29 days. At Orleton the absolute drought lasted 25 days and the partial drought 30 days. At Llandudno the absolute drought lasted 25 days and the partial drought 34 days. At Ardwick the absolute drought lasted 26 days and the partial drought 50 days. At Barnstaple the absolute drought lasted 28 days and the partial drought 36 days. At Haverfordwest the absolute drought lasted 26 days and the partial drought 30 days. At Seathwaite the absolute drought lasted 14 days, and no partial drought was recorded during this period.

The annexed table gives a comparison of the drought of 1887 with previous droughts. The waterworks at places dependent upon rainfall were during the past summer taxed to the utmost, and many towns had to be put upon short supply. In Swansea for about six months the supply to the town was restricted to a minimum daily supply of about 14½ gallons per head. The usual daily consumption of water per head of population varies considerably in different parts of the world. In Sydney it is estimated at 25 gallons, in Paris 36 gallons, while in London the amount is a mean between the last two amounts, and averages 30½ gallons per head per day.

In the metropolis no shortness or difficulty in the supply was experienced through the whole season, but in many country districts last year's drought will have convinced those who may have opposed the progress of a water scheme, of the necessity to provide an adequate amount of storage. In the north-west

THE DROUGHT OF 1887 COMPARED WITH PREVIOUS DROUGHTS.

County.	Station.	Commencement of Record.	Average 1870–79.		Driest Period Recorded.							Smallest Rainfall recorded any Whole Year.		
			Total in Year.	Seven Months, Feb. to Aug.	Seven Months, February to August.			Difference from Average.	Any Seven Consecutive Months.			Date.	Amount	Percentage of Average.
					Year.	Total Fall.	Per Cent. of Average.		Year.	Months.	Total.			
			inches	inches		inches		inches			inches		inches	
Lincolnshire ..	Boston	1826	24·92	14·12	1887	6·28	45	7·84	1887	Feb.–Aug.	6·28	1854	13·81	56
Hampshire ..	Strathfield Turgiss	1862	25·92	13·56	1874	7·78	57	5·78	1870	Jan.–July	7·58	1870	18·04	70
Suffolk	Culford	1859	26·20	14·43	1874	6·58	46	7·85	1874	Feb.–Aug.	6·58	1864	16·44	63
Middlesex ..	Camden Square	1858	27·24	15·07	1874	7·89	52	7·18	1873–4	Nov.–May	7·23	1864	16·93	62
Yorkshire	Hull	1857	27·30	14·67	1887	7·77	53	6·90	1857–8	Oct.–April	4·55	1864	18·27	67
Northumberland	North Shields ..	1860	28·02	14·81	1887	7·93	54	6·88	1887	Feb.–Aug.	7·93	1884	19·31	69
Worcester	Orleton	1831	33·26	18·31	1887	9·54	52	8·77	1887	Feb.–Aug.	9·54	1854	20·73	62
Carnarvon ..	Llandudno	1859	33·63	15·57	1887	8·83	57	6·74	1868	April–Oct.	8·67	1885	22·83	68
Lancashire ..	Ardwick	1854	36·73	19·79	1887	9·18	46	10·61	1887	Feb.–Aug.	9·18	1855	26·28	72
Devon	Barnstaple	1857	42·43	20·53	1887	9·00	44	11·53	1887	Feb.–Aug.	9·00	1864	26·43	62
Pembroke	Haverfordwest ..	1849	53·32	25·08	1887	12·06	48	13·02	1887	Feb.–Aug.	12·06	1855	34·21	64
Cumberland ..	Seathwaite	1845	134·95	60·88	1855	44·60	73	16·28	1855	Jan.–July	37·89	1855	88·31	65

of England storage for 120 to 140 days' supply is usually provided, but further south as much as double this capacity has been allowed.

London is at present supplied with water by eight private companies. Upon the south side of the river, principally by the Southwark and Vauxhall, the Lambeth, and the Kent Water Companies; and upon the north side of the river by the New River, the Grand Junction, the West Middlesex, the Chelsea, and the East London Water Companies. These companies are each controlled by special Acts of Parliament, as well as by the Waterworks Clauses Act 1847, and the Metropolis Water Acts of 1852 and 1871. The old London Bridge Waterworks, originally formed in 1582 by the construction of a water-wheel (the invention of Peter Morrys, a Dutchman, but free citizen), which was built in one of the arches of the old bridge, together with the wheels subsequently erected in four of the remaining arches of the bridge, became absorbed in 1822 by the New River Company, who now supply the area within their district with water from the river Lea and from chalk-wells. The Kent Water Company draw their supply entirely from chalk-wells; the East London Water Company from the river Lea, from chalk-wells, and, under an Act passed in 1867, from the river Thames at Sunbury.

The Metropolis Water Act of 1852 made it illegal for the Companies to supply water from the river Thames within tidal influence; consequently the Southwark and Vauxhall, the Grand Junction, the West Middlesex, and the Chelsea Companies removed their intakes from their original position higher up the river. The same Act also provided for all river-water intended for domestic use to be effectually filtered, and for all filtered water reservoirs within a radius of five miles from St. Paul's Cathedral to be covered. At our visit, made in August 1886, to Hampton, we saw the present intakes of the Southwark and Vauxhall Waterworks, and the additional pumping engines designed by our Member of Council, Mr. J. W. Restler, M. Inst. C.E., the engineer to the company; also the intake which adjoins these works of the West Middlesex Water Company, to which one of our members, Mr. William Hack, is the engineer. At this visit we also saw the intake of the Grand Junction Waterworks and the arrangements introduced by Mr. Alexander Fraser, M. Inst. C.E., the engineer to the company, for drawing water from the gravel beds of the district. It is well known in this district that the water stands in the gravels of the Thames valley, upon both sides of the river, at a considerable inclination towards the river, so that there is a large body of water making its way down the valley of the Thames, apart

from that which flows from the surface into the river. It was shown some years since by Mr. Thornhill Harrison, M. Inst. C.E., one of the Inspectors to the Local Government Board, that the underground waters in the valley of the Thames did not in all cases contribute to the flow of the river, and might therefore be tapped without affecting the volume in the river. The water admitted from the river above the intake to the storage reservoir when the river is disturbed by floods, was also seen by us at our visit to become naturally filtered through gravel screens prior to being pumped into the storage reservoir. The Southwark and Vauxhall Water Company have lately constructed works of a similar character for natural filtration. The Lambeth Waterworks Company, under an Act obtained in 1848, established works at Thames Ditton. Later on they removed their intake to Molesey, and availed themselves, under the direction of Mr. John Taylor, M. Inst. C.E., the engineer to the company, of the springs from the gravel-beds and chalk at West Molesey and Thames Ditton. The Chelsea Water Company also draw water from the river at West Molesey. The rapid spread of building operations in the neighbourhood of Hampton has led the Grand Junction Water Company to apply to Parliament, in the ensuing session, to draw water from the river Thames at Dorney, in the county of Buckinghamshire, and pump it to Kew, to be filtered before distribution.

During the drought of last summer, the companies continued to pump, the whole of the time, from the river, and did not draw on their storage to any great extent. The total volume which may be drawn daily from the river is limited to 110,000,000 gallons a day. The minimum dry-weather flow, just above the intakes, is about 350,000,000 gallons per day.

The usual summer level of the Thames at the intake of the Water Companies is about 23·38 feet above Ordnance datum. The effect of a flood or drought is not felt directly; it takes time to reach the river. Thus, the effect of the dry weather in June 1887, produced in August following a level of the tail-water at Sunbury Lock measuring 7 feet 4 inches above the sill, or 21·08 feet above Ordnance datum. In August 1887, the level of the tail-water at Teddington Lock during eight days fell to 6 feet 10 inches upon the lower sill, or 4·75 feet above Ordnance datum. This is the lowest level on record. At our October visit, last year, we witnessed the progress of the works of the new storage reservoir of the Grand Junction Water Company, near Hanger Hill, to the north of Ealing, which is now being constructed by Messrs. Aird & Sons, and designed to hold 52,000,000 gallons of filtered water.

The daily amount which may be abstracted from the river Lea is limited only by the amount that it can be depended upon to supply, and this is estimated at 50,000,000 gallons per day.

The principal object of the Metropolis Water Act of 1871 was to secure a constant service within the limits of supply. A constant supply is seen to be of great advantage in case of fire when the companies are required to supply water gratuitously, though they are not compelled to grant an unlimited supply to extinguish the fire. At the fire which took place at Mr. Whiteley's in Westbourne Grove last August, over three million gallons of filtered water were drawn from the mains of The Grand Junction Waterworks, in addition to a large quantity from the main of the West Middlesex Waterworks.

Under the Act of 1871 a Water Examiner is appointed by the Local Government Board, to see that the requirements of the Act of 1852 are complied with, and to issue periodical reports upon the quality and amounts of water supplied.

In places where a water supply is dependent upon underground storage the effect of a drought is not immediately felt, although the supply is not inexhaustible. The London basin is being drawn upon more and more every year. That this is a fact is borne out by the annual lowering of the water-level in chalk wells, averaging less than one foot per annum. All amounts drawn in excess of the rainfall which is collected must produce a lowering of the level of the store. The rainfall upon the outcrop of the beds contributes to the supply of the basin, but the water passes very slowly through the chalk-formation except where fissures occur. An artesian well in connection with the Artisans' Dwellings near Aldgate Church is now being sunk by the Corporation of the City of London, which will be bored, as at present arranged, 100 feet into the chalk. This well is intended to serve as an experiment for ascertaining the facility of supply upon a larger scale.

In dealing with water both the permanent and the temporary hardness have to be considered. In water from the chalk the hardness is mainly due to the presence of carbonate of lime. The scientific method of softening hard water prior to distribution, discovered by the late Dr. Clark in the year 1841, has been adopted at Southampton, Henley-upon-Thames, and other places. It consists primarily of adding a small quantity of lime, which combines with the carbonic acid and precipitates a sludge which can be allowed to subside or be removed by filtration. At the works above mentioned it is arranged to be carried out automatically and continuously in the time required for allowing the carbonate of lime contained in the water to be

precipitated. The hard water is pumped from the well into an automatic mixer, a small quantity, being diverted, is caused to pass through a cylinder containing cream of lime, whence it issues as a saturated solution of lime-water and rejoins the bulk of the hard water. The lime-water and hard water then flow through the mixer into a softening cistern, which is kept always full, and the water travels slowly from one end to the other, becoming softened in its course, and leaving the cistern with a milky appearance, owing to the action of the lime-water combining with the carbonic acid which held the chalk in suspension in the hard water. The water is then conducted to filters, where the deposit is arrested, after which it is received by a duplicate pump and forced into a service reservoir. The filters are cleaned out daily by steam power. This method of softening hard water is the plan adopted by the National Pure Water Engineering Company, Limited.

Drainage and Sewerage.

The Rivers Pollution Prevention Act, of 1876, aroused the authorities to the importance of a pure effluent. Costly experiments have been made, and various accounts compiled and printed. The most general plan for this purpose has been precipitation by lime, a method which was successfully adopted in Leicester a quarter of a century ago. Where plenty of suitable land exists, sewage irrigation, whether it pays for farming purposes or not, is decidedly the best system; but where the area available is contracted, the aid of chemistry is called in.

Last October we paid a visit to the Ealing Sewage Works, where lime is also introduced, with the use of a little clay, in the treatment of the sewage prior to discharging the effluent into the Thames. At these works, over which we were taken by Mr. C. Jones, the Engineer to the Ealing Local Board, we were shown four refuse destructors in which combustion is assisted by the introduction of a muffle furnace or fume cremator placed between the furnace proper and the main shaft.

At the Acton Sewage Works, which we visited the same day, and which were designed by Mr. C. N. Lailey, the Engineer to the Acton Local Board, purification was seen to be obtained by a combined process of precipitation and filtration. The material used for precipitation is the magnetic ferrous carbon and compound sewage salts supplied by the International Water and Sewage Purification Company. After precipitation in the tanks, the surface liquid is passed through a filter composed of granulated magnetic spongy carbon, and the purified effluent flows into the Thames.

The difficulty arising from accumulation of sludge is not now considered so much an objection to a precipitation scheme as formerly. Among sludge presses may be mentioned those made by Messrs. Johnson & Co., of Stratford, and those made by Messrs Manlove, Alliott & Fryer, of London, both in use at Wimbledon, those invented and made by Messrs. Drake & Muirhead, of Maidstone, in use at Acton, and Messrs. Friswell & Myall's press. The latter press was tried experimentally at Messrs. Owen & Co.'s Works in London, during the year 1886, with sewage from Crossness, and deserves mention, because it attempts to obviate the liability to crushing and blocking of the passages for the liquid portion of the substance operated upon. In some cases this may be due to the extensibility and compressibility of the cloth employed. The part formed with corrugations in an ordinary filter press is cast by Messrs. Friswell & Myall with a plane surface slightly recessed. The covering recommended consists of a wire cloth or gauze, or any incompressible woven material, such as asbestos. As we are promised a paper on the Acton Sewage Works by Mr. C. N. Lailey, and also a paper upon the Wimbledon Sewage Works by Mr. W. Santo Crimp, Assoc. M. Inst. C.E., we shall have an opportunity of discussing the relative merits of all systems. Where no lime is used in precipitation of the sludge, as at Acton, the manurial value of the precipitate is increased.

At the northern outfall of the Metropolitan main drainage situated at Barking Creek, Messrs. Mowlem, Burt, & Freeman are constructing works for the Metropolitan Board of Works, which I hope we may be able to visit next summer, prior to their opening towards the end of the year. There are three main sewers and an existing reservoir provided with penstocks for letting out the contents into the river when the tide is running out. A tank is provided for holding what is called iron water, which is to be forced into a separate lime-water tank. The use of iron salts, with or without a precipitant such as lime, is an old method in sewage treatment. In this case the iron water is to be mixed up with the lime-water and again forced into all three sewers, or into either one of them, by injectors. It will then be allowed to flow into new precipitating channels averaging 1000 feet in length, 13 in number, each provided with penstocks, so as to be used separately or together. It will be allowed to remain a certain time in a quiescent state to admit of the deposition of the sludge. After settling, the effluent will be run off at different levels by weirs into a culvert, which is laid under the precipitating channels, and will run into the existing reservoir. The sludge will run into a collecting culvert, and thence into special settling channels arranged at

different levels, after which it will be forced through pipes laid along a permanent jetty into steamers specially constructed for depositing at sea. The effluent will be stored in the reservoir when the tide is running up, and let out, as at present, when the tide is running out. A similar plan is contemplated to be followed in dealing with the southern outfall.

Trade and Profession.

If necessity is the mother of invention, still more is it the mother of inquiry; and general depression of trade led to the appointment in August 1885, of a Royal Commission, under the late Earl of Iddesleigh, to inquire into the present condition and future prospects of British industry. Upon this commission Mr. John Aird, M.P., one of our members, did good service. The Commission received reports from various Chambers of Commerce, and examined representatives of numerous associations connected with trade interests.

Their final report, which was presented to Parliament last session, shows the necessity of merchants and manufacturers in England and her colonies cultivating friendly relations with their customers in foreign countries, and of a personal investigation of such articles and machinery as are most needed in each individual country. Her Majesty's representatives, in their able diplomatic and consular reports, furnish most valuable periodical information, and are fully alive to the importance of maintaining our position as a manufacturing country; but they cannot be expected to possess the practical knowledge of particular branches of industry which can enlighten the British manufacturer.

Catalogues are too stereotyped to meet the demands of local tastes and requirements. If British industry is to maintain its due proportion of the increased trade of the world, we must advance with the times, and exercise that combined spirit of courage, enterprise, and energy which in past days so distinguished us as a nation. The remedy lies not in grumbling at bad trade, but in actively making inquiry, not by means of commercial agents, but by skilled travellers equipped with a knowledge of languages seeking to supply the wants of special markets at reasonable prices.

In order to prepare ourselves for the prosperity which an increase of trade is calculated to bring, manufacturers must be ready to avail themselves of all modern improvements in machinery for the execution of work.

The comparative cheapness of transport by sea, compared with the rates upon our inland railway system, is doubtless an advan-

tage to seaport towns in this country; but it must be remembered that the railway charges have the sanction of Parliament, and that, until it can be shown that the railway companies are making an undue rate of profit upon their capital, it is scarcely fair to their proprietors to demand a reduction. On the Continent railway carriage is cheaper than in this country, but the service is neither so rapid nor so frequent as with us.

The free development of canals, uncontrolled by railway companies, in places where they are likely to be useful, is recommended by the Commission, and the advantages which will be offered by the Manchester Ship Canal when complete will be watched with much interest. This canal will be 26 feet deep and 120 feet wide at the base, so that there will be ample room provided for the largest cargo steamers to pass one another in the canal.

The Imperial Institute will be capable of serving a good purpose, by helping to make us more conversant with colonial products and with the requirements of our colonial brethren. We also hope to assist, as an engineering society, by our union with colonial engineering societies, such as the Victoria Engineers' Association, to whom we give a cordial invitation to attend all meetings and visits of the Society, and to enjoy all the privileges of membership (except voting and the individual receipt of 'Transactions'), for six months, during the visit of any of their members to England. We exchange 'Transactions,' and have cordial relations with the Engineers' Association of New South Wales and the Canadian Society of Civil Engineers.

In this age of activity and great competition the profession of a Civil Engineer is no sinecure. When we consider that the Institution of Civil Engineers now numbers over 3800 corporate members, and more than 950 students, it behoves all young engineers to embrace every opportunity of improving their professional knowledge. Our Society is not a rival nor are we a branch of the Institution of Civil Engineers. On the contrary, most of our leading members are members of the Institution, and all our members acknowledge the status and usefulness of the Institution, established by Royal Charter in 1828, "for promoting the acquisition of that species of knowledge which constitutes the profession of a civil" (as distinguished from military) "engineer, whereby the great sources of power in nature are converted, adapted and supplied for the use and convenience of man." To be a member of the Institution of Civil Engineers is now very justly held to be a certificate of having attained some recognised position in professional practice.

With a view to assist in the collection and distribution of branches of professional knowledge, the Institution of Mechanical

Engineers was established in 1847, and our own Society in 1854, since which, the Civil and Mechanical Engineers' Society (of which I had the honour of being President in 1882) was established in 1859, the Iron and Steel Institute in 1869, and the Society of Telegraph Engineers and Electricians founded in 1871. The first summer meeting of the Institution of Mechanical Engineers was held in 1856, in which year they visited Glasgow. In 1877 they removed their headquarters to London. In addition we have also the work of the Association of Municipal Engineers and Surveyors, and of the Surveyors' Institution.

The object of these various societies is not to make men engineers, but to make them better engineers. We meet together as a social society to review the past, consider the future, and mutually to assist each other in every way. The experience of the past teaches us not to limit the possibilities of the future. Who can tell how far the discoveries of science may extend, or prophesy what shall yet be done or left undone in engineering enterprise? Civil engineering is limited only in its application by the progress of science, and serves to protect as well as to improve the means of production in different countries, both for purposes of export and import; hence our profession exerts a considerable influence over our national prosperity and the civilisation of our time.

We have facilities of transport and communication unknown at the commencement of the present century. When we hear that such and such an undertaking will not pay to work, it is one duty of the engineer to step in and devise such appliances as will so reduce the cost of labour that a fair profit may be obtained in carefully working the same. Depend upon it that it is only in proportion as we set ourselves firmly, and even obstinately, to master the difficulties before us, that we can succeed, and the real secret of the success obtained by those who have left footprints in the sands of time, lies not so much in their possession of any natural gift as in their distinguished promptitude and persevering disposition to inquire into causes and effects.

The use of all learning is its application. We study not merely to get up a subject, but to introduce that subject into actual practice. Our business has a higher object than earning a fee. We have to be persons of individual character, men who think everything out. We have to make good precedents as well as to follow them; hence our profession is a calling worthy of our best powers.

We hear a great deal about the importance of examinations in the present day. The Royal Institute of British Architects

(incorporated 1837) at present hold a voluntary examination, but in 1892 every person desiring to be admitted as a Fellow of the Royal Institute of British Architects must have passed the preliminary examination. The Surveyors' Institution obtained its charter of incorporation in 1881, and ten years after this date, examination for professional members, or fellows, will become compulsory. The Association of Municipal Engineers and Surveyors also conduct periodical examinations for municipal and local board appointments.

The proposed "Architects and Engineers Act" is framed upon the basis that the public have the right to be protected from incompetent professional men. The promoters propose to regulate the qualifications of practitioners in architecture, civil engineering, and surveying, and to institute a compulsory examination, conducted by the chartered professional bodies, for all desiring to be registered on the list of qualified practitioners. However useful the proposed registration of qualified practitioners might be, a high and strict sense of responsibility cannot be secured by legislation, nor can some of the best qualities requisite for a successful engineer be tested by examination. The engineer requires not only to produce a safe structure, with due regard to economy of material to be employed and labour involved, but he requires to be able to direct its execution with commercial dexterity, and the greatest art consists in the combination of honest business-like habits with scientific capability.

The Council of the Institution of Civil Engineers, as at present advised, do not propose to institute any examination of their own; but they have taken a very judicious step by requiring that in future every candidate for admission as a student shall produce a certificate of proficiency in the subjects of general education from some recognised public examining or educational body. In this respect they are following the example of the General Medical Council, which requires evidence of that kind, it being a rule that before any one is allowed to be registered as a medical student in a hospital, he must pass either the matriculation examination at one of the Universities or the College of Preceptors.

The class of students at the Institution of Civil Engineers was established upon the 26th June, 1867, and their special Friday evening meetings, coupled with their visits to works, form a valuable addition to the programme of the parent body.

Before concluding, allow me to address one word to the younger members of our Society. In my opinion, you cannot too long delay cultivating yourself into a specialist. If you possess special aptitudes, it is best to let time develop them,

and you will find your general knowledge of other subjects will enable you the better to adapt yourself to the special subject which you may be called upon to undertake. A young engineer with a future before him who cultivates one subject at the expense of the rest, is apt to become partial, and his work groovy. It should be your aim to learn a good deal about all the subjects connected with engineering, as much as possible about some one special subject, and to acquire a general acquaintance with the results of all things. Remember that no day should be wasted, as no experience is fruitless.

March 5th, 1888.

ARTHUR T. WALMISLEY, PRESIDENT, IN THE CHAIR.

THE EFFECT OF SEA WATER ON PORTLAND CEMENT.

BY HENRY FAIJA, M. INST. C.E.

THE subject of the paper which the author has the honour of reading before the Society this evening, is suggested by the reports which have been made public of certain failures of concrete work at Aberdeen, the failures being attributed to the chemical action of the sea on Portland cement. Such being the case, the paper is kept strictly within the province of cement and its use, and its behaviour when in contact with sea water, and all engineering questions are purposely avoided.

Portland cement has been used for marine purposes, in almost every conceivable shape and form, for certainly thirty or forty years, and although failures have occurred, they have never before been attributed to any chemical action taking place between the sea water and the cement. The investigation of the matter, therefore, becomes all the more interesting, and the deductions arrived at of very considerable importance. Engineers engaged in marine works are at the present moment in doubt whether a material which hitherto has been available under all circumstances and conditions, enabling many engineering works to be carried out which without it would have been impossible, a material which has given every satisfaction, is to be trusted. Undoubtedly, if the conclusions arrived at at Aberdeen are correct, one of the most valuable materials at the hand of the engineer is lost to him. Though a considerable quantity of concrete work has been carried out at Aberdeen, the failure seems to be restricted to a part of the graving dock. This dock was commenced in 1881, and opened in 1885, and at the beginning of last year (1887) it was found that certain portions of the walls had bulged. Mr. Smith, M.I.C.E., the harbour engineer, in conjunction with Professor Brazier, F.C.S., analysed portions of the damaged concrete, and reported definitely that the failure was due to the chemical action of the sea on the cement. Mr. Messent, M.I.C.E., engineer to the Tyne Commissioners, was then called in, and in

November last sent in his report. In the appendix he gives the results of several analyses of the concrete made for him by Mr. Pattinson, public analyst for Northumberland. Mr. Messent in his report supports and confirms the opinion expressed by Mr. Smith, viz. that the cause of failure is the chemical action of the sea on the cement.

If sea water chemically affects cement, it clearly does not matter the proportion in which the cement is used with the aggregate—i. e. it will affect a one to one concrete just as surely as it will a ten to one, so that the only part of the original specification which need be referred to is that for the cement; it runs as follows:—"The cement to be Portland cement of the best quality, from the rivers Medway and Thames, finely ground, and must pass without rubbing through a gauze sieve having a thousand holes to the square inch, without leaving more than 5 per cent. of its bulk as residue; otherwise it will be rejected. It is to weigh not less than 115 lb., and not more than 124 lb. to the imperial striked bushel. The tests, after having been mixed and cast in moulds (as directed), shall remain in the open air for twelve hours, and then be immersed in water for seven clear days, at the end of which time, if every five samples do not bear an average tensile strain or dead weight of 1000 lb. avoirdupois to a section of 1½ inch by 1½ inch, the cement shall be forthwith rejected. The minimum test must not be less than 750 lb., otherwise the cement will be rejected." The only other point which it is necessary to remember is that the concrete was mostly used according to Mr. Kinipple's method, in a plastic condition—i. e. it was allowed to partially set, and was then broken up and placed or rammed in position. Mr. Smith says:*—"The concrete was kept from two to four hours mixed before being broken up and deposited in the water by skips opening at the bottom. It had to be broken thoroughly, so as to flux together again in the water, when it formed a dense mass practically impervious to water." The theory of the chemical action of sea water on Portland cement is, to use Professor Brazier's own words, as follows:—"The lime of the cement becomes dissolved, but as instantly causes a precipitation of magnesia as contained in the sea water."

Before proceeding, the author would like to call attention to this question of magnesia in cement, which has also lately disturbed the equanimity of users of cement, and he wishes more particularly to make it clearly understood that magnesia in cement —i. e. incorporated in it in the course of manufacture, through the use of improper and unsuitable raw material—is in a very different form to the magnesia precipitated from the sea water.

* 'Min. Proc. Inst. C.E.,' vol. lxxxvii.

Magnesia incorporated in a cement is in a state similar to caustic or quicklime and on the addition of water acts in a similar manner, i.e. it heats and expands with considerable force; and if, therefore, it exists in any considerable quantity, it will cause the cement to "blow" or expand, and destroy the structure of which it forms a part: the explanation of this is, briefly, that the temperature at which a cement is burned is sufficient only to cause a perfect chemical combination between the lime, silica, alumina, and a part only of any magnesium carbonate which may exist in the raw materials; the remainder is only deprived of its carbonic acid by the calcination, and is left in the cement as free or caustic magnesia. Cement may be made, and the author has made, by heavy burning, cement containing as much as 5 per cent. of magnesia, which was perfectly sound, but he is of opinion that 3 per cent. should be considered the limit of safety; it need scarcely be added that 5 or 6 per cent. of free or caustic lime in a cement would be just as dangerous as the same percentage of magnesia. The magnesia in the sea exists principally in the form of magnesium chloride, and is precipitated as hydrate, and in this form it is perfectly inert; in fact, it is, to continue the comparison, similar to a slacked lime, and has no power of expansion. That it is found by analysis in cement which has been immersed in the sea, there is no question, but the author maintains that it simply fills the pores or interstices of the concrete, without in any way combining with and forming a constituent part of the cement.

The foregoing, though apparently a digression, is really of very great importance, because it shows a continuity of thought, from the effects of magnesia in cement, to the effects of sea water on cement, and suggests that the latter is considered as the corollary of the former; in the author's opinion incorrectly, for the magnesia in the two cases is in such very different forms that they are in no way analogous. Referring to Professor Brazier's analyses and experiments; he first analysed three samples of the original cement, in the form of broken briquettes, and also one sample of the cement in powder. In none of these did he find so much as 1 per cent. of magnesia. Analyses of several samples of the "decomposed cement" from the graving dock were then made, and in them the hydrate of magnesia varied from 13 to 21 per cent., at the same time the lime had decreased from 58·49 per cent. in the original sample to about 33 per cent. of carbonate and hydrate combined; he therefore inferred that some of the lime of the cement was dissolved, and some of the magnesia contained in the sea water precipitated. To satisfy himself on this point, Professor Brazier made the following laboratory experiment. Some of the cement in its

original form of powder, which contained practically no magnesia, was digested in a pint of sea water for four days; the analyses of the water and cement were made before and after, with the result that at the end of the four days the water was found to have gained 28·16 grains of lime, and to have lost 12·52 grains of magnesia. The argument seems conclusive, but the author thinks it is at fault, insomuch that, to keep the cement digesting is to keep it on the move, and therefore to prevent it from setting. It is well known that cement will set freely if left alone in sea water, and it seems reasonable to suppose that if the cement sets, disintegration, except from some cause within the cement itself, is impossible, and that if the disintegration of the cement takes place through the unsound nature of the cement, then the lime in it would be partially dissolved, and the magnesia in the sea water precipitated. The author is, therefore, of opinion that the cause of the failures of the concrete at Aberdeen is not to be looked for in the chemical action of the sea on a properly set Portland cement, but that they are due to the cement having never become properly set, or that the cement used was an unsound one, and disintegrated from causes within itself.

Experiments.

To prove this, the following experiments were carried out by the author, taking a cement having the following analysis:—

	Per cent.
Moisture loss at 212°	0·1
Carbonic acid	1·5
Sulphuric acid	1·38
Silica	23·55
Alumina and iron	9·2
Lime	62·6
Magnesia	1·01
Alkalies	0·6
	99·94

(1) He carried out Professor Brazier's experiments, and obtained practically the same results, i. e. after digestion in sea water for four days, with occasional heating, the lime was reduced to 47·9 per cent., and the magnesia increased to 8·47 per cent., but it must be noted that after the digestion of four days, even with the occasional heating, the cement was found to be partially set, and after drying it had to be broken up in a pestle and mortar before the analysis could be carried out.

(2) The second experiment consisted of putting about 2 oz. of cement in powder into two beakers, the one was covered with sea water and the other with fresh water, and these were examined from day to day. Both cements were set in a few

days, that in the fresh water being the harder; they were left altogether for five weeks, when the beakers were broken, and the set cements and the waters examined and analysed. The examination of both showed somewhat similar results; on the surface of both waters there was a film, and the upper surface of each cement was covered with a thin layer of soft sediment, about $\frac{1}{100}$ inch thick, which could be easily scraped off, the cement under being quite hard. After sufficient of each cement had been broken off for analysis, the pats were again placed respectively in sea and fresh water. The percentage of scum and soft sediment to the cement was

	Scum per cent.	Sediment per cent.
In the fresh water	0·48	2·27
„ sea „	1·37	3·89

Analyses of Several Parts.

	Sea Water.				Fresh Water.			
	Water.	Scum.	Sediment.	Cement.	Water.	Scum.	Sediment.	Cement.
		per cent.	per cent.	per cent.		per cent.	per cent.	per cent.
Silica	—	3·86	17·06	23·42	..	2·39	17·75	24·14
Alumina ..	—	2·71	7·94	9·43	..	4·16	6·64	9·88
Lime	1·68 gr.	85·37	46·1	61·84	..	93·3	71·5	61·77
Magnesia ..	trace	7·93	25·39	0·87	Not estimated.			

If the foregoing analyses are examined, it will be seen that, in the fresh water, the loss of about 1 per cent. of lime in the perfectly set cement is pretty accurately accounted for in the excess of lime in the soft sediment and in the scum. In the sea water, the loss of lime in the set cement and in the soft deposit is fully accounted for in the quantity found in the scum; and in the same way the loss of magnesia in the water, and the slight loss in the set cement, is all accounted for in the soft sediment and scum. In order to determine if there was any further precipitation of lime, the set cements which were returned to respectively sea and fresh water were examined in four weeks. A scum was noticed on both, and was found to amount to—

	Per cent.
In the fresh water	0·55
„ sea „	0·87

The fresh-water scum consisted almost entirely of hydrate of lime, while the sea-water scum contained as much as 25·31 per cent. of hydrate of magnesia, so that the actual extraction of lime from the cement was much about the same in both cases.

(3) Several briquettes were gauged with sea and fresh water, and tested with the following results, each test representing the average of five briquettes:—

Tensile Strength at—Days after Gauging.	Gauged with Fresh Water, and Placed in Fresh Water 24 Hours after Gauging.	Gauged with Fresh Water, and Placed in Sea Water 24 Hours after Gauging.	Gauged with Sea Water, and Placed in Sea Water 24 Hours after Gauging.
	lbs.	lbs.	lbs.
3 days	365	407	353
7 days	434	484	429
28 days	506	560	566

(4) A portion of one of the briquettes (which had been gauged with sea water, and been in sea water until tested) was, after being tested, placed in a beaker of sea water, which was maintained continuously for three months, night and day, at a temperature of about 110° Fahr.; the temperature varying from 104° to 125°; the loss of sea water, due to evaporation, was made good by the addition of more sea water, so that a fairly strong concentrated sea was obtained, and certainly, if sea water has the power of disintegrating cement, this piece of cement should have been in powder. However, it was quite hard, not the slightest sign of disintegration or blowing being visible. The cement was covered with a very hard scale which was with difficulty scraped off, and the cement itself was extremely hard. Analyses were made of the cement, the scale on the cement, the sediment in the water, and the water. The percentage of scale and sediment to cement was:—

	Per cent.		Per cent.
Scale	1·77 (estimated) ..	Sediment ..	0·2

PARTIAL ANALYSES AFTER CALCINATION.

	Cement.	Scale.	Sediment.
	per cent.	per cent.	per cent.
Silica	23·18	17·76	..
Alumina and Iron	9·68		
Lime	61·69	76·01	80
Magnesia	..	6·29	9

The sea water measured 6 oz., and it was found to contain 372 grains of total salts in solution, which quantity of salts would represent about 22 oz. of sea water, so that the cement during the latter part of the experiment was subjected to the action of a solution, maintained at a temperature of 110° Fahr.,

and containing more than three times the quantity of salts, including magnesia, due to ordinary sea water.

(5) The next experiment was to fill four moulds, two with cement gauged with sea water and two with cement gauged with fresh water; one of the former was placed in sea water directly, and the other was left in the air till set, and then placed in sea water; the two gauged with fresh water were treated in a similar manner, but were placed in fresh water; the time which each took to set was as follows:—

No. 1	gauged with	fresh water	set in	fresh water	3	hours.
„ 2*	„	„	„	air	1½	„
„ 3	„	sea water	„	sea water	4	„
„ 4*	„	„	„	air	2	„

These having been left respectively in sea and fresh water for twenty-eight days were tested for tensile strength, with the following results:—

No. 1	broke at	595 lb.
„ 2	„	540 lb.
„ 3	„	690 lb.
„ 4	„	650 lb.

From the results of these experiments the author is convinced that sea water has practically no deleterious action on a good cement; the experiments he has made have been carried out comparatively, as between sea water and fresh water, and practically similar results have been obtained in both cases, the only material difference being that, when sea water is used, the setting of the cement is retarded, and the ultimate strength is therefore deferred to a longer date; and this is also exemplified in the larger experiment made by the author seven years ago, published in a condensed form amongst the "Other Selected Papers" in 'Minutes of Proceedings of the Institution of Civil Engineers,' vol. lxvii. p. 349. More lime would be dissolved by sea water than by the same amount of fresh water; and in these comparative experiments it has been shown that both sea and fresh water dissolve a certain amount of lime from out of the surface of the cement. The precipitate in the sea water is the more bulky because the magnesia in the sea is precipitated by the lime, but the actual loss of lime in the cement is much about the same, whether the cement be in fresh water or in sea water; and there is, further, no doubt but that cement will set as well, though not so quickly, in sea water as it will in fresh.

Referring to the consideration of the manner in which most of the concrete at Aberdeen was made—viz. as "plastic" concrete

* These were both slightly soft on top surface when otherwise considered set.

or what the author prefers calling "reset" concrete. A "reset" concrete, to be of value, must be made with a slow-setting cement, and it must be broken up and placed or rammed *in situ* at a particular period during its progress of setting. If this is delayed too long, the "reset" concrete will never attain that hardness which it would under proper conditions. The author's experience of reset cements is that the breaking up of the mass and the regauging should be done at the moment when, by ramming, the original water of gauging can be brought to the surface, and that if that time is exceeded, and the concrete, after being broken up and rammed, remains dry, then the result obtained is not satisfactory, and the cement in this condition would undoubtedly be subject to the dissolving action of the sea on the lime. The following experiments with "reset" cement made by the author confirm this view :—

No. 1.—A Cement that set in One Hour, Neat Cement.

(Second gauging, 45 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging	482	596	..	..	..
Second gauging	414	550	..	..	..

No. 2.*—A Cement that set in Two Hours, Neat Cement.

(Second gauging, 20 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging	578	682	..	..	..
Second gauging	†465	†568	..	..	..

No. 3.*—The same Cement gauged with Three Parts of Standard Sand.

(Second gauging, 45 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.		
First gauging	..	280	284	..	..
Second gauging	..	†152	†133	..	..

* This is a cement adulterated with slag.

† On the second gauging of these the water or moisture could not be brought to the surface of the briquettes, showing that the setting had proceeded too far for the best results to be obtained on the regauging.

No. 4.—A Cement that set in Forty Minutes, Neat Cement.
(Second gauging, 20 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging	..	586	666	620	738
Second gauging	..*	648	558	547	602

No. 5.—The Same Cement Gauged with Three Parts of Standard Sand.
(Second gauging, 30 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	
First gauging	..	242	304	331	..
Second gauging	..	*222	202	143	..

No. 6.—A Cement that set in Four Hours, Neat Cement.
(Second gauging, 2 hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging	..	657	763	775	784
Second gauging	..	658	698	757	811

No. 7.—The Same Cement Gauged with Three Parts of Standard Sand.
(Second gauging, 2½ hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	
First gauging	..	264	320	321	..
Second gauging	..	230	329	322	..

No. 8.—A Cement that was Two Years Old, and took 24 hours to set, Neat Cement.
(Second gauging, 18 hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging	314	453	..	..	..
Second gauging	326	479	..	..	..

* This cement had become considerably slower setting, and consequently these briquettes were not so dry as those regauged for the three, six, and nine months.

No. 9.—A Cement that took Six Hours to Set, Neat Cement.
(Second gauging, 1 hour after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging	477	585	..	..	..
Second gauging	467	529	..	..	..

The noticeable feature in the foregoing tests is that, when a quick-setting cement is used, the "reset" cement always showed a very considerable diminution in strength, whereas in the slow-setting ones the loss is not so great, and in the one instance, No. 8, when the cement took 24 hours to set, the regauging of the cement actually increased its tensile strength. The whole of the results given represent the average of five briquettes in each instance, so that they may be considered to fairly represent the value of "regauged" cement. Mr. Smith, in 'Correspondence on Concrete Work for Harbours,'* expresses an opinion which entirely confirms the author's views of this material. He says:—"The final setting depended upon there being no addition made to the quantity of water absorbed in deposit. When the partly set concrete was not thoroughly pulverised and refluxed by the water in deposit, the mass remained porous, and the water disintegrated the cement and prevented it from setting."

It is scarcely fair, considering the progress which has of late years been made in the science of the use and testing of cement, to criticise a specification that was drawn up ten years ago, but as the nature of the cement used possibly had some influence on the failures which have occurred, it is necessary to briefly consider it. It is a very ordinary specification, one that any manufacturer would be able to comply with, but it does not in any way ensure a good and sound cement being delivered. The fineness asked for, 5 per cent. residue on a 1000-mesh sieve, would mean about 12 or 14 per cent. residue on a 2500-mesh, and that would be about the usual fineness asked for about five or six years ago, though now anything over 10 per cent. residue on [illegible] is considered coarse. The tensile strength demanded is, perhaps a little high, but is not such as would of necessity entail an unsound cement, and nothing is said as to whether it should be a slow or quick setting cement. The weight per bushel is altogether a delusive test; in the first place,

* 'Minutes of Proceedings of the Institution of Civil Engineers,' vol. lxxxvii. p. 214.

it gives no information as to the quality of the cement; and secondly, it is a test that varies with the age of the cement; and if users still think the weight is of importance, they should specify the age the cement is to be when weighed. The following experiments of the weights of two cements at different ages, which the author has lately made, are interesting and conclusive on this point:—

	No. 1.	No. 2.
	lbs.	lbs.
Weight when received	113	112
„ in one month	110	111
„ in three months	102	102
„ six months	100	99
„ nine months	97	
„ one year	95	
Loss in six months .. .. per cent.	11·5	11·6
„ in twelve months .. .. „	15·9	

It will be seen that a cement a year old weighs about 18 lb. less per bushel than when fresh, or a loss equal to 15·9 per cent., while at six months the loss is about 11·55 per cent. Then again, the finer a cement is ground the less it weighs per striked bushel, so that to ask for a heavy cement is tantamount to asking for a coarsely ground one. Though this is pretty generally known now, the following experiments made by the author several years ago may be of interest.

	Residue on No. 50 × 50 Sieve.	Weight per Bushel.
	lbs.	lbs.
No. 1 cement	6	109½
The same cement ground to all pass a 100 × 100 sieve	Nil.	100¼
No. 2 cement	25	114
The same cement ground to all pass a 50 × 50 sieve	Nil.	104
No. 3 cement	16	116
The same cement ground to all pass a 50 × 50 sieve	Nil.	109
No. 4 cement	14	116½
The same cement ground to all pass a 50 × 50 sieve	Nil.	112
No. 5 cement	33	118½
The same cement ground to all pass a 50 × 50 sieve	Nil.	105

The specific gravity is perhaps a better test than the weight per bushel, because the fineness of grinding does not affect it, but it, of course, also diminishes with the age of the cement,

though not to so great an extent. The following examples show this:—

	No. 1.	No. 2.	No. 3.	No. 4.
Specific gravity when received ..	3·16	3·175	3·16	3·12
,, in one month ..	3·055	3·125	3·13	3·109
,, in three months ..	3·095	2·965	3·084	2·985
,, in six months ..	3·016	2·93	3·018	2·995
,, in nine months ..	2·969	2·915	3·015	2·985
Loss in six months .. per cent.	4·55	7·71	4·49	4·006

Thus at the age of six months the average specific gravity of the four cements has diminished 5·189 per cent., as against 11·55 per cent. loss of weight per striked bushel, a difference in results which almost suggests that one of the experiments is at fault; but the difference may be accounted for, if it is remembered that the cement having a specific gravity of 5 per cent. less, would fall into the bushel measure proportionately lighter, and thus the difference in the two results would be accounted for, and an additional reason arrived at for the abolition of the weight per bushel test.

Referring again to Professor Brazier's report, it will be seen that the analysis of the cement used in its original form was as follows:—

	Per cent.
Alumina and oxide of iron	13·1
Silica	20·92
Lime	58·49
Magnesia	0·33
Sulphuric acid	0·82
Water of chemical combination	2·74
Carbonic acid	3·6
	100

A cement with this analysis can only be considered of medium quality. It has a great excess of alumina, is very deficient in silica, and contains 3·6 per cent. of carbonic acid, which represents nearly 5 per cent. of lime. It was evidently a lightly burned cement, and if it weighed 115 lb. per bushel, in accordance with the terms of the specification, its weight must have been due entirely to coarse grinding. This analysis was made only a few months ago, years after the cement was used, and the 5 per cent. of lime which when the analysis was made was in the form of carbonate, was so much free or caustic lime when the cement was used, i. e. lime that was not in chemical combination with the silica, alumina, and other components of the cement; to diagnose the cement from the analysis with the assistance of the specification, it was probably,

when used, a quick-setting cement that developed considerable heat during setting, that attained its ultimate strength in a short time, and would then probably fall off a little in strength. If the same cement was used now, when all the free lime had been converted into carbonate, it would be slower setting, and would not heat; it would not, however, attain its ultimate strength for some considerable time. Generally, it may be stated as a fact, that no cement can be produced which contains no free lime, though it may be reduced to very small proportions, and that, therefore, given a well-proportioned cement so far as silica, alumina, and lime are concerned, the only safeguard is that it should be well warehoused in bulk and turned over more than once, so that such caustic lime as may be in it shall be reduced to carbonate. In the author's opinion no cement should be used for important works until it is three months old, and during one month of that time it should have been laid in a layer, not more than 3 feet thick, in a good dry warehouse, and have been turned over at least twice. The practice of using cement direct out of the sacks or barrels is most pernicious, and offers a direct premium on bad results. Even in a laboratory, a cement laid out to cool in a layer barely 1 inch thick, and turned over every day, will often, in fairly warm weather, not be fit to use in a week's time, so how can it be expected that cement, packed tightly in barrels, can take up sufficient carbonic acid to convert whatever caustic lime may be in its composition into carbonate, and thus purge itself of its dangerous property? The author submits that a Portland cement that is well ground, and can be proved sound, is invariably strong enough for any purpose for which cement is used.

The soundness of a cement, i. e. its freedom from expansion or contraction, or what is known as "blowing," can be determined with absolute certainty by several methods. There are three well known, viz. Sir John Coode's, the German and French method, and the author's. The two former have the advantage that they can be carried out without any apparatus, and in a rough-and-ready manner; but they are not so sensitive as the author's, and a week has to elapse before the determination can be made. Against the disadvantage of requiring an apparatus, the author's process has the great advantage of enabling a decided opinion to be given in a few hours. It is fully described in a paper which the author had the honour of reading before this Society in 1885.

One point only remains to be alluded to. It is recommended that some of the repairs to the graving dock shall be carried out with Roman cement. No doubt there are sufficient reasons for preference being given to this material; but if sea

water damages Portland cement it will equally affect Roman cement. An experiment made by the author with Roman cement similar to that carried out by Professor Brazier with Portland, showed that, after digestion in sea water for four days, it had lost 17·39 per cent. of its lime, and had taken up all the magnesia due to the sea water in which it had been digested; so that, so far as the action of the sea water is concerned, there seems no choice between Portland and Roman cement.

In conclusion, the author trusts that he has been able to satisfy cement users that good Portland cement, properly used, is practically not deleteriously acted upon by sea water. Nothing is permanent; the rains dissolve the lime from out of the limestone rocks, and by precipitation deposits are formed elsewhere, building up the geology of the future as the geology of to-day has been built up. It is not in reason to think that Portland cement should be able to resist forces to which nature succumbs; but for practical purposes Portland cement is a permanent constructive material, whether it be used in air, in the river, or in the sea. In all cases, precautions must be taken in its use, commensurate with the risks to which it is to be exposed. But so far as the chemical action of sea water is concerned, it may be disregarded where a good and properly used Portland cement is concerned; and the failures at Aberdeen must be attributed to one of two causes, or to a combination of them—either the cement was bad, or was used when too fresh, and hence disintegration ensued; or by the improper manipulation of the concrete, whether plastic or otherwise, the set of the cement was disturbed, and it never afterwards became properly set and hard.

DISCUSSION.

The PRESIDENT, in inviting a discussion, said he was sorry that Professor Brazier was prevented by illness from being present. A letter had been received from his assistant expressing his regret. A communication had also been received by Mr. Faija, from Mr. Messent, of Tynemouth, which he would now ask the Secretary to read.

The Secretary accordingly read the following letter:—

"*Concrete Works, Aberdeen.*

"TYNEMOUTH, *March 4th*, 1888.

"MY DEAR SIR,

"I am obliged by your letter of 2nd inst., and sorry that I am only able to give a hurried reply as to the plastic concrete. I see that Mr. Smith's statement in the 'Minutes of

Proceedings Inst. C.E.' might be misunderstood, but in my report (p. 5) I think you will agree with me that there is no ambiguity as to the construction of the dock within a coffer-dam. I have no time to get a representative to attend your meeting to-morrow, so avail myself of your kind offer to transmit to the meeting the few observations that I am able to make in the absence of a copy of your paper.

"From the abstract it appears that you have arrived at the conclusion that Portland cement concrete properly made cannot be deteriorated by sea water; and that the deterioration of the concrete at Aberdeen is due either to 'inherently' bad cement having been used, or to the injudicious use of it in a plastic form. The result of a large number of experiments comparing the behaviour of cement when gauged in sea water and when gauged in fresh water is also given as a reason for your conclusions, but no explanation as to the nature and extent of the experiments.

"As no concrete was used in any of the deteriorated work at Aberdeen in a plastic form that reason for your conclusion may be dismissed.

"Next as to 'inherently' bad cement having been used: having had an opportunity of examining the original test briquettes made from the cement used, also the mortar and concrete in portions of the work that have not been affected, I am able to state that the cement used was not 'inherently' bad, but of at least an average good quality. In this opinion I am supported by that of Mr. Pattinson, public analyst for Northumberland (see report, pp. 12 and 28), and these opinions would be further corroborated if the names of the manufacturers (all of good repute) were stated.

"There only remain in support of your conclusion your experiments, the nature of which is not stated in the abstract.

"About two or three months ago you published in the 'Engineer' an account of experiments which you then considered conclusive on the same subject. If, as is possible, they are reproduced, you will I trust pardon me for remarking that I do not by any means consider them conclusive.

"The experiments that I refer to were as to two cement briquettes. One was gauged with sea water, and, after being sufficiently set, it was immersed in a bath of sea water for 28 days, after which it was tested for tensile strength and proved to be stronger than the corresponding briquette gauged and immersed in fresh water; a result which I should have predicted had the immersion lasted for 28 months instead of days.

"The chief ingredient in sea water that can injure cement is magnesia, of which sea water contains about $\frac{1}{500}$ part of its

weight; now in gauging a cement briquette with sea water, probably a quantity equal to 20 per cent. of its weight would be used, and in the subsequent immersion it might absorb at the most 10 per cent. more. This would make the briquette after its immersion contain 30 per cent. of sea water, or of magnesia $\frac{3}{10} \times \frac{1}{500}$, or say about $\frac{1}{1700}$ of the weight of the briquette; as it is generally allowed that cement may contain at least 1 per cent. of magnesia, the above quantity ($\frac{1}{1700}$ part) could certainly do no harm, and any effect that it might have would probably be beneficial.

"The effect of the briquette being kept in the sea-water bath after the first immersion and absorption, would be to prevent the ingress or escape of the water absorbed (which had deposited its magnesia), and this water would prevent the exudation of any more water or magnesia. The arrangement would therefore be as effective in *preventing* the deterioration of the briquette from sea water, as if it had been kept out of the water altogether.

"It is not contended that cement concrete will suffer deterioration from simple immersion in still sea water. Deterioration takes place only when sea water is repeatedly absorbed (when there must be an intermediate exudation or evaporation), or where there is a forced percolation of sea water. (See report, pp. 14 and 15.)

"It is possible that you may have made experiments under these (the only) circumstances under which concrete is stated to have been deteriorated. If not, I think that you will admit that you are hardly justified in arriving at a conclusion adverse to those who, in addition to examining the work in detail on the spot, have made exhaustive experiments, and given long and mature consideration to this most important subject.

"I have pleasure in enclosing for your acceptance a copy of my report, on which I have marked in pencil some of the paragraphs which I think bear most importantly on the case.

"Very sincerely yours,

"PHILIP J. MESSENT.

"HENRY FAIJA, Esq."

At the invitation of the President, Mr. FAIJA then made some opening remarks, saying that he was sorry that neither Mr. Messent, Mr. Smith, nor Professor Brazier could be present. In the reports of Mr. Messent, Mr. Smith, Professor Brazier, and Mr. Pattinson, and also in the long communication from Mr. Smith in the 'Minutes of Proceedings of the Institution of Civil Engineers,' six months before the failures at Aberdeen were

observed, there was abundant evidence that the cement was in some cases injudiciously used, and that the quality of some of it was at all events a little doubtful. There was, therefore, sufficient cause to account for the failure of the concrete, without seeking to attribute it to the chemical action of the sea water on the cement. One analysis by Professor Brazier showed the cement to contain as much as 66 per cent. of lime, and 5·54 per cent. of carbonic acid. He did not think that anybody would maintain that such a cement could be safely used. Most of the cements analysed by Mr. Pattinson contained about 62 per cent. of lime, and so far might be considered sound cements; but they all appeared to contain a larger proportion of carbonic acid than should be present in a good cement. The chemical action of sea water upon cement was, however, a most important matter, and he trusted that the discussion would bring out information from which a definite opinion might be formed on the question.

Professor L. F. Vernon-Harcourt said that he took great interest in the subject, having had much to do with concrete work in the sea. It appeared at first sight as if the conclusions in Mr. Messent's report were borne out, but it did not contain the report of Mr. Smith, and therefore it did not explain the way in which the concrete work was carried out; but Mr. Messent's letter, just read, was not in accordance with what the author of the paper had said, for it stated that the concrete in the part of the work that failed was not put in in a plastic form. To what, then, was the failure due? There were two points in Mr. Messent's report which nothing in the paper thoroughly answered. In the first place Mr. Messent took two briquettes, one of which he had made with neat cement, and one with three parts of sand to one of cement; and, as appeared from the report, after immersing them in sea water he exposed them to rapid evaporation near a hot plate, and repeated these operations several times; and he found that on being tested they gave much lower results than they would have done had they not been subjected to the action of the sea water. From this Mr. Messent inferred that some interchange had taken place between the magnesia in the sea water and the lime in the cement; that is to say, that the magnesia, which existed in sea water as chloride and sulphate took the place of the lime in the concrete in the form of hydrate of magnesia, which was insoluble; sulphate and chloride of lime taking the place of the magnesia in the water. Of course, if such an interchange really occurred, one could understand that Portland cement had become of comparatively little value in course of time, though Mr. Messent gave a certain amount of reassurance in his report

by saying that the mischief was only rapid when there was a constant passage of sea water through the concrete, in which case the displacement would occur, if the artificial experiment could be accepted as evidence of what would occur under natural conditions. Mr. Messent chiefly attributed the failure of the concrete to there being too much sand in it, and to it consequently being sufficiently porous to admit the passage of sea water through it.

He recollected hearing Mr. Hayter's opinion expressed at the Institution of Civil Engineers about a year ago, to which the author had referred. It was directed to the question as to whether the cement did not itself contain magnesia, and not to the question of magnesia being introduced from sea water.

In France some cement was used which had a large percentage of magnesia in its composition, and it was found that the cement mortar in the work (which in that case was done out of water) blew and expanded, owing to the absorption by the magnesia of the moisture in the air, much damage being the result. It was, however, a totally different case from that of a good cement, almost or entirely free from magnesia, becoming affected by sea water by the absorption of magnesia from it. It certainly surprised him (Prof. Vernon-Harcourt) to see that Mr. Messent was going back to Roman cement, because he recollected that when, many years ago, he had to take charge of the Alderney Breakwater for two years, Roman cement, which had been used up to the time that he went there, was discarded in favour of Portland cement. It was considered that Roman cement, though setting very quickly and therefore useful in some cases, was liable to perish after a time, and some of the failures which occurred at the Alderney Breakwater were attributed to the use of Roman cement.

Recurring to Mr. Messent's experiments, there was a second point which he should like to ask the author to explain. Mr. Messent in his report spoke of having fastened a briquette of three of sand to one of cement over the mouth of a bottle, so as to force the sea water to percolate through the briquette by immersing the empty bottle to some depth. According to Mr. Messent, the water which percolated through the briquette into the bottle under pressure, contained a great deal more lime than the actual sea water; while a considerable portion of the magnesia in the sea water was found in the briquette. In that case it would seem as if, by means of the percolation under pressure, a certain amount of magnesia was really taken in by the cement, or, at least, set free from the sea water; and that the lime from the cement was taken up by the water. He should like to hear the author explain how it was that the

briquettes which were acted upon by the sea water, as mentioned in Mr. Messent's report, became less strong than they were before. If sea water, by mere percolation, would substitute magnesia for lime in Portland cement, the duration of concrete work in the sea was uncertain, unless provided with an impermeable skin. He thought, however, that deterioration would have already manifested itself in sea works of concrete, where exposed to repeated immersions and evaporation, if the natural chemical action were as decided as appeared in the experiments. More searching investigations were needed to confirm or dispel the doubts, as to the permanence of Portland cement concrete exposed to sea water, which had been raised by the experiments referred to. Any decision as to the real cause of the failure at Aberdeen must be withheld till the adequacy of the suggested cause had been proved, and in the absence of evidence of the original soundness of the cement and of its method of deposition being unimpeachable.

Mr. Gibbons said, as representing Messrs. Robins and Co., one of the oldest firms of cement manufacturers in the country, that it seemed to him rather strange (putting aside the chemical analysis of cement), that after so many years of constant use of cement in the shape of concrete, there should be this one failure at Aberdeen. He had not heard of any other failure of any magnitude. During the last thirty years or more his firm had supplied very large quantities of cement, under various engineers, most of whom were engineers of high repute. They had never yet had a cement that contained too much magnesia, so that it had hydrated or blown. A very quick-setting cement, such as plasterers were fond of for running mouldings, had a tendency to blow. The only object of those persons was to get their work done quickly. Of course if bad materials were used in the mixing of the concrete blocks, or if there was too much sand, so that the sea water could percolate through, it was very possible that failure might result in consequence of the action of the sea. Most of the manufacturers agreed with him in this, but it was one of those scientific points which they had not gone into. Under such conditions it was possible that the work might crumble, but he had not heard of any instance of the kind. There were other manufacturers present who could, no doubt, make similar statements as to the cement which they had supplied. Analyses of cement were something new. Most makers were now having their cements analysed. So far as magnesia was concerned, he found that his cements kept within one per cent. of that body. He was sure that if the cements contained as much magnesia as they sometimes heard about, they would detect it in a very few hours after their pats were put up,

because the fresh pats were put in water almost immediately they were set, and ten hours would show whether they were sound or not. He was sure that it would be the conviction of most makers that if the cement would stand for ten hours, it would stand for ten years. The failure at Aberdeen seemed to have created a very great sensation amongst engineers. He did not think that the failure was due to magnesia. He believed that it was more due to the way in which the materials were manipulated. He had seen thousands of tons of concrete shovelled into position as soon as mixed, and there it had remained, as hard as a rock, to the present day. He fancied that the use of plastic cement opened the door to those who used it to kill the cement; for when the cement began to set, it ought not to be disturbed again, and if it was so disturbed, a great deal of the life was taken out of it.

Mr. G. R. Strachan asked whether, before the discussion went any further, one point could be settled, viz. whether the cement at Aberdeen was used in the plastic condition or not. It had been said that it was so used, but Professor Vernon-Harcourt and Mr. Messent had said that it was not. He would suggest that they should have an authoritative statement on the subject.

Mr. Faija said that, when the paper was written, he had not before him Mr. Messent's report. The paper was written under the conviction that plastic concrete had been used for the whole of the works, but it appeared that it had been used only in part. The letter from Mr. Messent which had been read by the Secretary, stated distinctly that, in the work that had failed, the concrete was not used in a plastic form.

Mr. W. T. Dent said that, after the evidence that had been produced by the chemists engaged upon this question, it must be admitted that (under special conditions) sea water possessed the power of decomposing Portland cement, due to the action of the magnesium chloride which the salt water contains, a fact to which attention was called many years ago. The lime in the cement is dissolved out as calcium chloride and magnesia is deposited as an inert substance, which (if not washed out) simply serves to fill up the pores of the cement without exerting any further deleterious action. This reaction has been shown to take place when cement in a state of powder is placed in sea water, and also when there is a continuous percolation of sea water through a cement which is not sufficiently impervious to prevent its penetration.

From experiments he had made, it had been found that a hollow block 6 inches square and 12 inches in length, consisting of one part of cement and three parts of sand, the thickness of the cement and sand being 2½ inches, when exposed to a

pressure of 8 feet of water was sufficiently porous to allow a fall of water in a pressure tube of ½ inch in diameter, to the extent of 9 inches in an hour; whereas a similar block made of equal parts of cement and sand, under the same pressure, was found to be practically impervious. It is evident that the concrete used at Aberdeen was from some cause of too porous a character, which must have been due, either to the use of a badly made cement, or to its injudicious admixture with the sand and stones forming the aggregate of the concrete. With respect to the quality of the cement there is no evidence to warrant the conclusion that the cement (as delivered) was of inferior quality, although, judging from the terms of the specification, it was not sufficiently ground, which would tend to increase the porosity of the concrete. With regard to the analysis of the original dry cement, the number given for carbonic acid, 3·6 per cent., is undoubtedly high, but this is in probability due to the sample having absorbed carbonic acid during the time that elapsed between the date at which the sample was taken and that upon which the analysis was made, and not, as has been suggested, to an excessive quantity of caustic lime in the cement when delivered.

With respect to the action of magnesia, although any considerable amount is not desirable in Portland cement, which generally contains not more than from one to two per cent., yet it must be recollected that many very excellent cements contain a much larger proportion. The reported failure of cement owing to the injurious action of magnesia has in some cases been due to forgetfulness of the fact that it must be regarded as to some extent taking the place of lime. In an example given of the evil effects of magnesia, analysis showed that the lime and magnesia added together amounted to 72 per cent., an excess of basic material which would quite account for the failure of the cement, even if it had consisted entirely of lime.

The failure of the concrete at Aberdeen must serve to impress upon engineers the necessity of the concrete used for sea-walls being sufficiently solid to resist the passage of water, under whatever pressure it is likely to be subjected to, and when this is the case there does not appear to be any reason for supposing that a well-made concrete will not sustain the character for durability which the experience of forty years has served to establish.

Mr. F. RANSOME said he was certainly surprised when the report was first made of the failure of the concrete at the Aberdeen graving docks, and regarded the statements as exaggerated. As an engineer who had been connected with the profession for fifty years, he looked upon Portland cement with confidence, and

each year of his experience confirmed that confidence. He believed Portland cement, when properly made and properly applied, was one of the most useful materials which an engineer could employ. Thousands upon thousands of pounds were annually expended in the construction of docks, breakwaters, and other submarine works, and if they were now to be told that the action of sea water was such as to deteriorate the cement used in such structures, and so bring about their ruin, what was to be their confidence in the future? When he first heard of the failure it occurred to him that there must be something wrong either with the quality of the cement or with the mode of its application. With regard to the use of cement concrete in what was termed the "plastic" state, he considered it an essential point with Portland cement, or any other cement, that from the moment the material commenced its setting action it should be left undisturbed. If it was disturbed after that time, it was disturbed at the expense of the structure. It was true that they might break up a cylinder of cement and produce it in blocks, and the blocks might get hard, but he should have no confidence in their power to resist the action of the sea. With reference to magnesia he differed from some of the other speakers. He knew that it was a deleterious substance in cement, and considered the excess of two or three per cent. of magnesia very objectionable. But the effect of magnesia as an ingredient of cement was a totally different thing from the effect produced by the action of magnesia from outside the surface of the cement. He quite agreed with the author that sea water had no injurious effect upon cement. On the contrary, he was inclined to think that it was advantageous if the cement had been properly made, properly worked, and had become properly set.

Mr. P. Stuart exhibited some samples of granolithic stone mixed with salt water, which had been exposed to the action of sea water for about four years. As to the dock at Aberdeen, he saw it in the course of construction, and observed the cement broken up after it had been set. He could not say whether the cement was good or bad, but he thought that the fault at Aberdeen was very easily brought home to the engineer. They were using an improper material to mix with Portland cement, and it was being put down indiscriminately, and was not properly packed in. They might have been purposely putting it down so as to allow the passage of sea water through it. During thirty years' experience he had never known a single piece of cement work to go wrong in sea water when properly executed. At Aberdeen gravel obtained in the neighbourhood was used. This was a very rough

material and very varying in size, and soft sea sand was used to fill up. What was really made was just a filter, and nothing else. Aberdeen was the home of a perfect material, but the engineer did not use it, although it was lying at his hand. He used a material which really he had no right to use, and using it he did not crush it as he ought to have done, in order that it might become thoroughly combined with the cement. He (Mr. Stuart) remarked to the man in charge, "Well, you will have some trouble with this yet," and the man turned round and said, "Ay, man, ye dinna ken muckle aboot it." He (Mr. Stuart) replied, "Well, somebody will know about it some day, and somebody will have to answer the question." That question had now arisen, and we have the result. If the dock at Aberdeen had been constructed of the material now exhibited on the table there would not have been the trouble which had now arisen. A dock at Glasgow 570 feet long had been constructed of it, and it was perfectly tight and sound.

Mr. J. T. Hurst said that he had twenty-five years' experience of Portland cement in the War Department, and he had never known an instance in which it had failed, owing to its being mixed with salt water.

Mr. J. Francis said that Mr. Faija had suggested that contractors should always lay out their cement for a month in layers two or three feet deep, and turn it over once or twice during that time; but there was not always the opportunity of laying out cement for a month beforehand, inasmuch as jobs were not all large ones, nor did they always last a long time, as, for instance, where important repairs had to be undertaken at short notice. He thought it would be a very good plan if the manufacturers would lay themselves out to provide the users of cement with material ready for use. They might charge a little more for it if necessary, but let it be ready. A certain amount might be kept stored up, and manufacturers would find out in the course of time what quantity they ought to be provided with. Of course in works of any magnitude the engineer could store the cement for the requisite time more cheaply and conveniently than could be done by the manufacturer.

Mr. Alexander Clark said that he had expected the author of the paper to show how he had come to his conclusions. He appeared to think that the presence of magnesia might possibly be of no consequence, and its influence might be set aside. But Mr. Messent's report so carefully stated the method of his experiments that at first sight it did not seem possible to avoid the conclusion that the presence of magnesia in the Portland cement had had a deleterious effect in the case of the Aberdeen dock, yet the proof was not entirely conclusive. The author, on

the other hand, started with the idea that the use of "plastic" cement in the dock was a cause of the failure; and a great many of the conclusions to which he had come appeared to be founded upon that wrong assumption. Both Mr. Messent and Mr. Smith had contradicted the statement as to the use of plastic cement in the portions of the work which had given way, and it was well to accentuate the fact, as it would prevent undue weight being given to the author's conclusions, so far as they were based on this assumption. There was so much Portland cement used in works all round the coast, that it would be a very serious matter if they were to find out at this time of day that sea water had such an injurious effect as to decompose that material. Such a conclusion would cause much alarm, and if it could be shown to be borne out by what had occurred at Aberdeen, the sooner they gave up the use of Portland cement, the better. He thought that the varying pressure caused by the rise and fall of the tide, and the washing of the waves against the concrete work, and the suction caused by the recoil of the waves in stormy weather, were much more likely than any supposed chemical action to be the causes of the destruction of the concrete. The mechanical action would wash away the cement bit by bit; but it had yet to be proved that the deposit of magnesia in the pores would really destroy the cement. If, as one of the speakers had said, the magnesia merely replaced lime, and was itself harmless, they had nothing to fear. The idea of preserving the works by putting a skin of plaster over the face or back of the wall, was one of the most ridiculous ideas that were ever conceived. The whole mass ought to be equally proportioned, and solid throughout, before the work could be considered thoroughly reliable.

Mr. D. L. Collins said that what he had to say was entirely from a manufacturer's point of view. His firm (Gibbs & Co.) had manufactured a very large quantity of cement for use in marine and dock work, and had never had a single failure reported. They had also advanced a little beyond some of the older manufacturers, and relied a great deal upon chemistry, employing a resident chemist, so that when they obtained Mr. Messent's report, they submitted it for his examination and report, which was as follows:—

"Grays, 19*th Dec.*, 1887.

"*Cause of Damage at Aberdeen Graving Dock.*

"I have carefully read through the reports and analyses of Professor Brazier and Mr. Pattinson relating to this matter.

"I notice that Mr. Pattinson has analysed three briquettes

representing cement supplied by three different makers, and I am struck by the excessively high amounts of carbonic acid found, viz. 4·23, 7·45, and 5·08 per cent. respectively.

"During the past two days I have determined carbonic acid in a series of briquettes made from some cement with the following results :—

Briquette 5 years old contained	.. ..	0·82 carbonic acid.
,, 2 ,, ,,	.. ..	0·74 ,,
,, 9 months old ,,	.. ..	0·92 ,,

being practically the same in this respect as when originally made.

"It is well known that good Portland cement seldom contains more than 1·5 per cent. carbonic acid, and when thoroughly burned, 0·75 to 1 per cent. is about the average amount, so that I am of opinion that the briquettes examined by Mr. Pattinson were made from a cement originally containing an excess of carbonic acid.

"Professor Brazier attributes the carbonic acid found in Portland cement concrete to the action of sea water, but Mr. Pattinson shows that the effect of washing a briquette in sea water was an unmistakable removal of this body.

"It is much to be regretted that only one analysis of the cement itself is given, more especially as this shows a dangerous amount of carbonic acid, viz. 3·60 per cent.

"From the figures above given, and from the results of the analyses of the various samples of concrete as published, there appears good reason for doubting the soundness of at least some portion of the cement used, and certainly for believing that the concrete was irregularly mixed.

"To these causes, in my opinion, the mischief is mainly due.

"HAROLD H. SLATER, F.C.S., London."

He (Mr. Collins) had had some tables drawn out showing the analysis of their cements, which he believed would also fairly represent the bulk of the cement manufactured on the Thames. In none of those instances would the carbonic acid be found to be more than $1\frac{1}{2}$ per cent. In the briquettes in question it was shown to be 3 or 4 per cent. Those who understood the subject would see that the cement was not properly burnt. As to the quality of cement, if engineers would specify the chemical proportions of the lime, and require the lime to be thoroughly combined, paying also particular attention to fine grinding, they would get a much safer cement than they got when they depended upon tensile strain and weight per bushel.

The PRESIDENT asked Mr. Collins to let the Society have a copy of his tables of analyses.

Mr. COLLINS said that he would do so with pleasure.

Mr. W. H. COLLET (Formby & Co.) said that his firm had for a great number of years supplied cement for some of the most important marine works in the world, and he had never before heard of such a failure as that at Aberdeen. It was a very significant fact that no such failure had occurred, considering that the coasts of the United Kingdom and other parts of the world were literally girdled round with large works in cement concrete, which were all liable to be affected in a similar way by the action of sea water. One large work (which might be called a representative one) he had taken peculiar interest in, viz. the Newhaven breakwater and sea-walls. He believed that, so far from any failure having taken place there, the Newhaven Harbour Company contemplated the completion of the breakwater at once, the original scheme of which was founded on the earlier Aberdeen work. From the evidence that had been given the meeting that evening as to the manipulation of the concrete and the inferior quality of the cement used, he (Mr. Collet) felt more impressed than ever that the failure must be attributed to those two causes.

Mr. PERRY F. NURSEY said that his experience of the action of sea water on cement was somewhat limited, but still he thought it was valuable, as showing that sea water was quite harmless in respect of deteriorating the quality of cement. About fifteen years ago, while building some sunk powder magazines on the Essex coast, owing to the difficulty of obtaining fresh water, he had to mix the concrete for the foundations, gauge the cement, and soak the bricks mainly in salt water. The work was, nevertheless, carried out satisfactorily and stood well to the present day. From time to time during construction he had tested the cement itself and the brickwork put together both with cement gauged with salt water and with fresh, and he could not detect any difference whatever. This, he thought, absolved sea water from the imputations cast upon it.

Mr. P. W. MEIK said that he confessed that when he read Mr. Messent's report he could not quite accept it. It seemed to him that the reasoning was a little weak in one or two points, and he did not consider that Mr. Messent had proved his case. He appeared to have fallen into an error of which scientific men should be extremely wary, that of drawing conclusions from an insufficient number of experiments, the strongest argument in the report being based upon one single experiment. This experiment also depended upon chemical analysis, rendering its value still more doubtful. He did not wish to say anything

which would offend the feelings of gentlemen interested in chemistry; but so far as his experience had gone, if one sent a sample to a chemist, and gave him some sort of idea what conclusion one wanted to arrive at, the analysis would go a long way towards it. He did not blame chemists for this, it was a very difficult thing to avoid personal bias in such matters; he had often experienced it himself. Mr. Messent had hardly sufficiently explained why it was that if concrete was affected by sea water acting upon it internally, it should not also be affected, though perhaps in a modified degree, by sea water acting on its face. He (Mr. Meik) knew places on the coast where concrete which had been put down twenty years ago was now almost as hard on the face as granite.

He fancied that the main ground of difference between Mr. Faija's views and those of Mr. Messent was to be found in two facts: first, that Mr. Messent had not had an opportunity of examining the cement as it arrived; and second, he was of course obliged to rely upon statements as to the method of doing the work. He did not agree with Mr. Messent that the cement had been proved to be in good condition when it arrived, and even the recent analyses did not appear to be satisfactory. As to the other point, he had visited the works during their progress, and did not consider the method of doing the work was a proper one, the concrete being allowed to lie for several hours before being deposited. Mr. Smith at that time held very strong views on the subject, and it was curious that he should have changed his views within a very short period afterwards. He thought the cause of the failure might probably be found in one of the directions he had indicated, without going so far as Mr. Messent had done to look for a cause which was so contrary to general experience.

Mr. J. W. Wilson, jun., said that the author had brought a very important subject forward. In the early days of the use of concrete a considerable amount of discredit was thrown upon it in consequence of certain failures, which were the results of its faulty employment, rather than of its inherent nature. He had hoped that his friend Mr. A. E. Carey would have been present that evening, as from his experience he could have thrown much light upon the subject of the evening. He (Mr. Wilson) had lately been corresponding with several cement manufacturers, and he had been much struck with the statement of several of them, that they had not made any experiments upon the action of sea water on Portland cement, and it seemed that they did not intend to make any. The matter evidently required a much more thorough investigation than had yet been given to it. One manager to a cement company

had said that he did not consider that it was for the manufacturer to make experiments, for manufacturers could provide whatever they were asked for. He hoped that this was a matter which would not be allowed to rest, and that the conclusion arrived at would be that the particular failure of which they had heard was not such as to affect the general use of cement for sea work, but was due to one or more of the causes which had been brought before the meeting that evening.

Mr. W. C. ANDERSON said that he had received an invitation to attend the meeting, as his firm (Hilton, Anderson, & Co.) had supplied some of the cement for Aberdeen. He was at Aberdeen last summer, and having seen so much in the papers about the failure of the work, he walked out to the breakwater and found that the concrete in part of that structure had also been damaged. He did not wonder at the sea making inroads upon it, for it struck him that in some parts of the work the proportion of cement was exceedingly small. Probably those parts were built before Mr. Smith's time. He had no opportunity of forming any conclusion as to the dock. He saw some of the creamy substance that had been spoken of, but did not bring it away for analysis.

As to the proper weight of cement per bushel, that was a matter upon which engineers differed very much. He continually got specifications ranging from 106 lb. to 120 lb. a bushel. The weight per bushel was certainly a most delusive test. Some months ago the case of a breakwater for Australia was brought under his notice, for which the engineer specified 118 lb. a bushel. When he got the report from the resident engineer six months afterwards he found that the cement did not in any case exceed 106 lb. a bushel. The difference in weight had been lost in six months. His attention had been drawn to the analysis as regarded magnesia, and in no instance had he known it to exceed two per cent. In the analysis of French and German cements they would find a much larger proportion. About one per cent. might be taken to be a fair average proportion in English cements.

Mr. GIBBONS said that it had been stated by Mr. Wilson that manufacturers did not carry out experiments in the use of cement. But there was scarcely a cement-maker on the Thames or Medway who did not use some hundreds of tons of concrete on their own works for foundations, water-tanks, and various other things. He had some tanks which were made some twenty years ago, and they were as tight now as upon the day they were first put up. He had a foundation 20 feet thick for a large engine, and it had never shown any sign of failure. The storing of cement by manufacturers for three or four months was im-

practicable, on account of the enormous amount of warehouse room which would be required for the purpose. Hundreds of thousands of tons of cement were made on the Thames and Medway every year. The turning over of the cement, which was done in some instances, entailed an extra charge for manual labour. He mentioned this to remove any wrong impression to the effect that manufacturers did not want to do more than they could help. They were anxious to do the best they could for their customers, and to get as much credit for their cement as possible.

Mr. Wilson said that he must have been misunderstood. What he intended to say was that manufacturers had made no experiments especially with reference to the effect of sea water.

Mr. R. E. Middleton, being too unwell to address the meeting, requested permission to send in a written communication.

Mr. Faija, in replying, said he thought that notwithstanding the statements which had been made in the course of the discussion as to what had been seen at Aberdeen, it must be taken that Mr. Messent's statement was correct, and it would not be fair to assume, after what he had said, that any of the concrete on which he had reported had been used in the plastic form.

Professor Vernon-Harcourt had asked a question with regard to the absorption test made by Mr. Messent. If that test was examined, the reason of the falling off in the strength of the briquettes would be apparent. Mr. Messent says, "I therefore arranged for two similar briquettes, after their immersion in and absorption of sea water, to be warmed near a hot plate until the greater part of the absorbed water had evaporated, and the process was repeated until the total quantity of water absorbed by and evaporated from the briquettes amounted to (according to the sum of the differences of the weights taken, and recorded each time) 57·31 oz. in the neat briquette, which weighed dry 25·25 oz., and 111·12 oz. in the mixed, one to three, briquettes, which weighed 23·25 oz.

"I did not think it necessary to have these briquettes analysed. . . . The two briquettes were afterwards tested for tensile strength, when the neat cement briquette broke with a strain of 126 lb. per square inch, and the mixed briquette with a strain of 91 lb. per square inch. The breaking strain for corresponding briquettes made of the same cement and at the same time (and not subjected to sea-water influence), being 415 lb. and 144 lb. respectively, showed a diminution of strength of 69·64 per cent. on the neat cement, and 36·8 per cent. on the mixed, one to three, briquette after the absorption of the magnesia. The neat cement briquette, however, showed several cracks before it was broken, such cracks not being apparent in the one to three briquette."

After a briquette had been repeatedly saturated with sea water and then dried over a hot plate, he (Mr. Faija) did not think that it was necessary to assume that the magnesia deposited by the sea water in the pores of the briquette was the cause of its loss of strength, but rather that the deterioration was due to the repeated and alternate wetting and drying. In fact, Mr. Messent himself said that the briquette made of neat cement showed several cracks.

The forced percolation of sea water through the concrete seemed to be the reason assigned by Mr. Messent for the failure at Aberdeen, the continued percolation dissolving out the lime of the cement and depositing magnesia. A given quantity of sea water would absorb twice as much lime as the same quantity of fresh water. If, therefore, sea water percolating through a concrete would destroy it in, say, a week, it was only necessary that fresh water should pass through it for a fortnight to wash out an equal quantity of lime and destroy the cement. But they all knew that when cement had been in water for a short time, whether it was salt water or fresh, a scale or crust formed on the surface, and that, whatever quantity of lime was dissolved from the cement when first immersed, none was dissolved after this crust was formed. There was, therefore, no reason why a cement should be destroyed by a forced percolation of water, for this crust would protect it and considerably diminish, if not altogether stop, further filtration.

Since it had been definitely stated that the concrete in question was laid in coffer-dams, there could be no doubt that either the cement must have been a bad one, or that the concrete was badly made, or the water was let on to it before it was set, and the cement washed away from the aggregate. As stated in the paper, he (Mr. Faija) was of opinion that magnesia as precipitated from the sea was a perfectly inert material, which had no influence for either good or bad on the cement, and was totally different to magnesia as found incorporated in a cement in course of manufacture; and, as this view was entirely antagonistic to that propounded by Professor Brazier and Mr. Messent, he had been particularly anxious to have Mr. Dent's opinion on the subject, more especially as it was really the crucial theoretical point in the whole discussion.

Mr. Messent, in the letter which had been read to the meeting, seemed to doubt whether he (the Author) had any right to venture an opinion in opposition to those who had examined and reported on the work. He was very sorry that Mr. Messent was of that opinion. He hoped that whatever he (the Author) might say in opposition to Mr. Messent, he would take in the same good part he had himself taken Mr. Messent's re-

marks. The matter was one for scientific discussion and not for personal antagonism. The whole object of the paper was that the question of the effect of sea water on cement might be thoroughly discussed and settled, so that engineers might still have that confidence in Portland cement which they had had hitherto, and he trusted that his endeavours to deal with the subject would be of service to the profession.

He might add that he was now engaged in carrying out some experiments on forced percolation of both sea and fresh water, through briquettes composed of three parts of standard sand to one of cement; the cement being the same as that which was used in the experiments detailed in the paper. The head of water was 21 feet and the direction of filtrations was reversed every two or three days. The experiments would necessarily take some time to complete, but as none have hitherto been carried out in this direction, he trusted they would be of some value. It must not be forgotten that, whether right or wrong in his conclusions, to Mr. Messent must be given the credit of having originated the idea.

CORRESPONDENCE.

The following written communication from Mr. R. E. MIDDLETON was afterwards received:—

I will, if you will allow me, make a few remarks on the subject of the paper read by Mr. Faija and on the discussion which followed.

I think, if I may be permitted to say so, that the point at issue was, to a considerable extent, lost sight of. More than one speaker maintained that because we are informed by Mr. Messent that plastic concrete was not used in the work, the failure of which is reported, while Mr. Faija believed that it was used in this part of the work, therefore his argument falls to the ground; but this is so far from being the case that the issue is only narrowed by the elimination of plastic concrete from consideration. Mr. Faija says that the failure of this work is not due to the presence of magnesia in cement, but to one of two things: either the plastic concrete was improperly used and mixed, or the cement employed was such as was not suitable for the work. If, then, plastic concrete was not used in the work where failure resulted, according to Mr. Faija the cement was in fault, and in this view I thoroughly agree.

All the analyses, whether made by Professor Brazier or Mr. Pattinson, go to prove, in my opinion, that the cement examined was an under-burnt cement, which contained an undue and dangerous proportion of free lime, which would be quite sufficient

in itself to account for the disintegration and degradation of the concrete. Secondly, I gathered from what was said by most of the speakers that they considered Mr. Messent's case to be proved, because his experiments agreed with the analyses of Professor Brazier and Mr. Pattinson, so far as the absence of a proportion, smaller or greater, of the lime originally contained in the cement from all the samples examined was concerned, while in all was found an added amount of magnesia; and because in a test made by Mr. Messent with a jar $1\frac{3}{4}$ inch in diameter at the neck, corked with a briquette of concrete and placed in the sea under a head of 18 feet of water, a proportion of the lime was found to be washed out, while a considerable quantity of magnesia was added to the sample. But this is never denied by Mr. Faija; if I understand him rightly, he grants the statements made in the several reports in full, but he denies the deductions drawn from them. He says, in fact, and this is the whole gist of the argument throughout, and cannot be too strongly urged on the notice of his hearers, that what Professor Brazier, Mr. Pattinson, and Mr. Messent have looked upon as a chemical action, tending to destroy the concrete by disintegration, is simply mechanical; that a proportion of lime is certainly washed out of the concrete by the action of sea water acting under pressure, and that the same effect, only to a smaller extent, would be produced by the action of fresh water under similar conditions; also that a proportion of magnesia is left in the concrete by the sea water which has passed through it; but he says, and, I believe, perfectly correctly, that such magnesia has already hydrated and is perfectly harmless and inert, and has no more effect on the concrete than would the introduction of so much fine sand. Mr. Messent found that 94 oz. of water passed through his briquette made with one of cement and three of sand in 87 hours, but that 7 oz. passed through a similar briquette in two hours; if this rate of percolation had been maintained the quantity passed in 87 hours would have been 304 oz.; therefore it is moderately obvious that the rate of flow was not maintained, and in my opinion it would have soon ceased altogether. The thickness of the briquette was $1\frac{1}{2}$ inch, therefore if with this thickness 94 oz. of water passed in 87 hours, $\frac{1}{40}$ part of this amount would pass through a wall five feet thick in the same time if made of the same materials; for the retardation is due to friction simply, therefore the quantity of water passing through the wall, supposing the flow to be constant, the head constant at 18 feet and constantly maintained (all of which suppositions are exaggerations of the facts), would be at the rate of $\frac{94}{40}$ oz. of sea water per area $1\frac{3}{4}$ inch in diameter of the face of the wall in 87 hours, or at the rate of 38 oz. per square foot of face

area in 24 hours, or 13,870 oz. of salt water would be passed through one square foot of face area in a year. This sea water would contain about 27·5 oz. of magnesia, which would be introduced into five cubic feet of concrete in one year, or about $\frac{1}{326}$ part by weight of the whole, and, as remarked above, even this quantity is greatly exaggerated.

I consider Mr. Faija's paper a most valuable one, and I trust he will continue his experiments and will clear up to the satisfaction of all, not only of those who already agree with his conclusions (as I do myself), but of those who at present dissent from him, this question so all important to engineers.

[Table.

TABLE OF CEMENT TESTS AS PROMISED BY MR. D. L. COLLINS.

Average Tensile Strength of Gibbs & Co.'s Portland Cement, on $1\frac{1}{2}$ in. × $1\frac{1}{2}$ in. Section. Representing the breaking of 5000 Briquettes.

	1882.		1883.		1884.		1885.		1886.		1887.	
	7 days.	28 days.	7 days.	28 days.	7 days.	28 days.	7 days.	28 days.	7 days.	28 days.	7 days.	28 days.
1st January ..	1020	1325	930	1110	1012	1230	940	1275	950	1270	955	1110
15th „ ..	995	1275	900	1130	980	1140	945	1180	965	1215	1015	1200
1st February	990	1235	1000	1290	1030	1230	1015	1325	1035	1310	1035	1310
15th „ ..	915	1155	1045	1345	885	1100	1000	1130	1060	1260	1040	1235
1st March ..	980	1235	1060	1320	1025	1270	1017	1300	935	1290	910	1120
15th „ ..	1055	1350	985	1320	1020	1280	1045	1160	930	1165	1020	1140
1st April ..	1050	1185	970	1070	900	1225	957	1250	1060	1195	1135	1300
15th „ ..	1000	1230	1130	1260	957	1195	940	1220	1035	1225	980	1210
1st May.. ..	965	1275	1025	1205	937	1200	1160	1380	975	1215	985	1205
15th „	1002	1280	950	1255	950	1230	1072	1320	975	1270	1035	1335
1st June ..	1010	1255	1020	1120	1050	1130	1170	1400	1050	1210	990	1295
15th „ ..	947	1200	995	1245	960	1210	1175	1320	985	1190	985	1200
1st July ..	975	1080	900	1140	950	1150	945	1210	1000	1145	970	1200
15th „	960	1270	945	1140	967	1170	1092	1310	997	1335	850	1120
1st August ..	937	1235	1040	1190	880	1030	1027	1380	1060	1430	970	1215
15th „ ..	1065	1310	1100	1260	950	1070	935	1350	965	1215	1120	1305
1st September	970	1385	955	1090	965	1290	1050	1270	970	1190	895	1190
15th „	1005	1410	985	1180	965	1115	935	1225	1012	1200	875	1235
1st October ..	1140	1295	935	1110	975	1145	950	1220	1025	1300	1050	1290
15th „ ..	1140	1265	925	1080	1040	1320	1065	1200	1020	1310	1037	1350
1st November	1080	1260	1100	1330	1185	1400	980	1210	1120	1360	1050	1280
15th „	970	1105	1000	1130	1080	1220	925	1105	965	1275	1100	1440
1st December	1050	1350	970	1290	1030	1325	1110	1335	1115	1370	1045	1310
15th „	965	1100	1185	1340	1035	1205	1060	1320	1025	1300	1070	1340
Average ..	1006	1252	1043	1206	988	1202	1021	1266	1009	1260	1005	1247

N.B.—These results were obtained by a skilled workman, whose sole occupation is to gauge cement, and the briquettes were broken without any time condition.

With a time specification of 15 seconds per 100 lb., or under ordinary circumstances of outside testing, the results would have probably been about 25 per cent. lower, viz.:—

7 days' average.	28 days' average.
750 lb.	950 lb.

April 9th, 1888.

ARTHUR T. WALMISLEY, PRESIDENT, in the Chair.

THE WIMBLEDON MAIN DRAINAGE AND SEWAGE DISPOSAL WORKS.

By W. SANTO CRIMP, A. M. INST. C.E., F.G.S.

THE author proposes to give the history of these works from the period of their commencement in 1876 to the present time. The leading features of the original scheme will be presented; their weak points will be emphasised; the remedies applied will be described; and criticism will be invited, in order that these works may be rendered still more perfect than they are at present.

In most papers, descriptions of works recently carried out are given, and it frequently happens that little is heard subsequently of their success or otherwise; but as failures are often much more instructive than successes, due prominence will be given to those which have occurred in the works to be described.

Wimbledon is a well-known suburb of London, its name being inseparably connected with the great annual meeting held on its unrivalled common by the National Rifle Association. The sanitary engineer may find something instructive in this meeting, as there the problem of sewage disposal is most satisfactorily solved, so far as the temporary requirements of the "canvas city" are concerned.

The population of the district is about 25,000, and its area is 3220 acres, 640 acres of which form the Wimbledon portion of the common, the remaining 500 acres being in Putney parish. The north-western corner of the common adjoins Richmond Park, and these two beautiful open spaces form a magnificent lung, for ever available as a great health-giving function by the vast metropolis.

The district is, roughly, rectangular on plan, a little under three miles in length and two in breadth. It may be divided into three zones, as shown by the contour lines on the plan: the plateau on the south-east of the London and South-Western Railway, having a mean elevation of about 50 above O.D.; the slope connecting this area with the common; and the table-

land of the common itself, the mean elevation of which is 180 above O.D.

Three main outfall sewers have been constructed for the drainage of the district. The sewage from that serving the low-lying portion requires to be pumped, whilst that from the other two gravitates to the sewage disposal works.

The high-level outfall commences at the small tanks situated on the sewage farm, passes under the railway by means of a syphon in cast-iron pipes, 18 inches in diameter, and is then continued in brickwork, its section being the old form of the egg shape, its size 2 feet 3 inches by 1 foot 6 inches, and its gradient 1 in 686. At the point A on plan the two principal branches join; these, in their turn, being the recipients of the contents of the various subsidiary sewers. A storm overflow is provided at the point shown on the plan. This portion of the system receives the sewage of about 3500 persons.

The mid-level outfall commences at the sewage works, and passes through part of the sewage farm and the cemetery in a westerly direction, and is the receptacle for the sewage of the intermediate zone. It is constructed of brickwork as far as the Cottenham Park Road, its section being oval and its sizes 3 feet by 2 feet as far as the Wimbledon Hill Road, and 2 feet 3 inches by 1 foot 6 inches as far as Cottenham Park Road. Its remaining portion is of 12-inch stoneware pipes, the various branch sewers being of like construction. The gradient of the brick outfall sewer is 1 in 1320, whilst its branches vary from 1 in 300 to 1 in 8. The population served by this outfall is now about 8000.

The low-level outfall also commences at the sewage works, and passes in a southerly direction to the point C on the plan, whence its course is nearly due west. Its original course is shown on the plan, the dotted lines representing portions now no longer in existence. Its sizes and gradients were as follows:—First portion, 3 feet 9 inches by 2 feet 6 inches; length, 6300 feet; gradient, 1 in 2041. Second portion, 2 feet 3 inches by 1 foot 6 inches; length, 3700 feet; gradient, 1 in 2000. Third portion, 18-inch stoneware pipes; length, 4400 feet; gradient, 1 in 2370. Fourth portion, 15-inch stoneware pipes; length, 3550 feet; gradient, 1 in 1860. At its termination a flushing tank holding 6000 gallons of water was constructed.

Not only was the design of this outfall bad as regards its gradients, but the inverts were carried through at the junctions of the smaller with the larger portions, without the rise necessary to prevent retardation of flow by the backing-up action of the constantly augmented volumes in the larger portions below. The outfall was, in short, a horizontal cesspool so far as the

smaller portions were concerned. The remedial works designed and carried out by the author will be described later.

The branch sewers discharging into this outfall are nearly all constructed of 12-inch stoneware pipes having good falls. The population served is 13,000.

There were several miles of sewers in existence at the period when these works were commenced, and these were retained for the disposal of surface water. The author has added largely to these works, their extension having become necessary in consequence of the rapid development of the district. The most important work carried out in this connection is the western outfall, which discharges into the Beverly Brook at Coombe Bridge. It is a brick circular sewer, 4 feet in diameter at its commencement, gradually diminishing in size to 18 inches. Concrete tubes were largely used in its construction as regards those parts having diameters of 18, 21, and 24 inches. The cost of these works was about 6000*l.*

All new roads now made up under the 150th section of the Public Health Act are provided with duplicate means of drainage, and the entire scheme now offers a good example of the separate system, the advantages of the axiom, "the rainfall to the river, the sewage to the land," being both fully recognised and acted upon. Large quantities of roof water are still admitted to the sewers, however, with the consequence that in heavy storms they are sometimes surcharged. This was notably the case in the thunderstorm of August last, but the fall then was quite exceptional. The author does not consider it desirable to carry drains for rain-water to the backs of houses in close contiguity to the soil drains, as there would be great risk of unprincipled persons connecting their soil drains with the rain-water drains in the event of a stoppage of the former, and for this reason all down pipes at the backs of the houses are connected with the soil drains.

The low-level outfall soon became a source of trouble so far as its smaller portions were concerned. The normal flow of the sewage was at the rate of 8 feet per minute only; nearly all the solids were deposited, and after being in use for six years, the sewer was two-thirds full of solid matters. The smells emitted from the manholes were, it is needless to say, very offensive.

In 1885 the author was requested to report on its condition, and subsequently to suggest a remedy.

It was decided that if a new outfall was found to be necessary, it should be capable of being extended to the north-western limit of the building land of the district, when future requirements rendered it necessary so to do. Two courses presented themselves: either to construct a new outfall from

the existing pumping station, at a depth of about 20 feet below the present outfall, or to construct a smaller pumping station at a site situated in the western portion of the district, reconstructing the smaller parts of the original outfall, and improving it elsewhere. The latter scheme was shown to be by far the more economical. The necessary plans were prepared by the author, and the works carried out in 1885–6.

These works, as designed, comprised the improvement of the tortuous portions of the outfall in Hartfield and Graham Roads, by carrying the main sewer in a straight line from Palmerston Road to Graham Road, and by constructing new 12-inch pipe sewers in place of the old brick outfall, which was broken up. The new sewer was carried under the houses in tunnel, no openings being made in any of the gardens, thus avoiding damage to property and claims for compensation. Its size is 3 feet 6 inches by 2 feet 4 inches, thus being large enough to admit of the sewer men passing through. It was constructed of "Candy's" bricks in Portland cement mortar, and the heading was filled in solid with Portland cement concrete.

The new outfall eastwards from the Wimbledon and Croydon Railway, as designed, was 21 inches in diameter, and its gradient was 1 in 1000. At the point E, its size was reduced to 18 inches, and its gradient was 1 in 900; its termination being the new pumping station, at which point the invert level was 42 O.D. That portion of the outfall, 21 inches in diameter, has not, as yet, been constructed, in consequence of the fact that private lands would have to be crossed, which lands will shortly be developed for building purposes, when the work can be carried out without large claims for compensation being made.

Eastwards from the pumping station, the new outfall commences with an invert level of 17·50 O.D.; it is for a length of 1000 feet circular in section, 3 feet 9 inches in diameter, its gradient being 1 in 900, this portion being a tank sewer for the storage of the sewage when the pumps are not at work. Its western continuation is 15 inches in diameter, with a fall of 1 in 600 to the Durham Road, whence it is 12 inches in diameter, with a fall of 1 in 500, there being a flushing tank at its termination. These portions of the outfall are constructed of concrete tubes, embedded in concrete, the depth at which they are laid varying from 22 to 30 feet.

The pumping station is provided with a pair of single-acting ram-forcing pumps, the ram being 12 inches in diameter, with a stroke of 24 inches, working at a speed of twenty strokes per minute. These pumps are operated by a pair of "Otto" $3\frac{1}{2}$ nominal horse-power gas engines, the machinery being

arranged to work interchangeably, if desired. The ascertained consumption of gas is one cubic foot for each 112 gallons raised, the lift being 33 feet. The sewage is lifted into a tank, holding nearly 20,000 gallons, which, when full, discharges its contents by means of a penstock into the 18-inch outfall, which is thus most effectively flushed, at least twice daily.

The old 18-inch outfall was quite freed from deposit for a considerable length on the commencement of the flushing, but much sand and heavy detritus still resisted the action of the water, as its original velocity was lost, and in order to clear this out the author had a strong copper ball, 15 inches in diameter, made; this ball was placed in the sewer—at the manhole next above the commencement of the deposit—and with each flush worked its way forward, thoroughly cleansing the portions passed through, and bringing out quantities of detritus, including also two bricks. A totally unexpected incident occurred in connection with its use; a long length of sewer had been cleared when the ball stopped and remained at the same place for upwards of a week. The line attached broke, and an opening from the top was made, when the sewer was found to be in a state of collapse; the remainder of the outfall was examined at frequent intervals, and there is little doubt but that all the pipes for a distance of 500 yards are crushed, the stoneware of which they are constructed being unable to resist the pressure of the clay stratum in which the sewer is constructed; the depth below the surface of the crushed portion being from 15 to 18 feet. The pipes were jointed with clay, and thus had not the strengthening assistance of a cement joint, but even with cement joints the author would not trust to pipes unsupported with concrete at the depths named.

In addition to the new works described, five automatic flushing tanks were also constructed, each provided with one of Rogers Field's annular syphons. The position of these tanks is shown on the plan.

The total cost of these remedial works has been about 12,000*l.* They have exercised most beneficial influence, not only as regards the main drainage works themselves, but also as regards the sewage, which now arrives at the sewage works in a fresh state compared with its putrid condition before these works were undertaken.

All the sewers, as originally designed, were ventilated by means of the man-holes in the ordinary way, the sewer air escaping at the street level. The ventilators were placed at an average distance of 160 yards apart.

Complaints, however, have been of frequent occurrence, not only as regards the old imperfect sewers, but also of the more

perfect portions, which have no connection with those less favourably circumstanced.

The causes of the smells are well known to those having the care of sewerage schemes, and the generation of foul air in the sewers is, in the opinion of the author, inseparable from all such systems. The ebb and flow of the sewage, leaving the sides of the sewers alternately wet and dry, is one factor; another is the careless way in which house drains are laid, leading to frequent partial or entire stoppages; in such cases the sewage being putrid before it enters the sewer. Then there are stoppages due to foreign substances, such as scrubbing brushes, &c., lodging in the intercepting traps, which traps are placed between the houses and the sewers in this district, in accordance with the model bye-laws. In the case of the main sewers, the author on one occasion found a 12-inch sewer blocked in consequence of the accumulation of grease at the junction of the drain from a large residence. In another case, a sewer of the same size, laid at a depth of 18 feet, was blocked by the roots of a tree; and, indeed, the cases of partial or entire stoppage of sewers or drains officially coming under the author's notice during the past six years exceed 300 All these cases are factors in the production of foul smells, and are inseparable incidents in connection with the working of a large sewerage scheme.

At one time the middle-level outfall was much complained of as a producer of foul smells, particularly in warm weather; but on making experiments on sewer ventilation, the author found that in warm weather, when the temperature of the atmosphere is higher than that of the sewer air, the latter passes down the hills, and this outfall was the receptacle of the sewer air generated in the branches, which are laid in the hilly roads on its north side. All these branches have excellent falls, and are possibly as perfect as sewers can be, yet they produce foul air in abundance. In cold weather the direction of the flow of the sewer air is upwards, and in order to regulate this flow the author inserted a syphon trap between each branch and the main outfall, thus isolating each branch from the general system, and rendering comparatively easy the subsequent disposal of its sewer air.

The author entirely agrees with Professor Attfield's views, recently enunciated, that the necessity for the ventilation of pipe sewers, as now carried out, does not exist. The grids at the street level are an abomination, and should be abolished. If all houses were properly drained, sewer air could not enter them through the house drains, and if, under these circumstances, sewers were unventilated, it is difficult to see that any evil results could ensue, excepting of course in the case of

large sewers, in which men are employed. As, however, a large number of the older houses are not properly drained, vent should be provided for the foul air of the sewers, in order that there should not be sufficient pressure to admit of its being forced into these houses. In the opinion of the author, this object may best be accomplished by means of pipes, carried up trees, houses, or other convenient objects, or by specially constructed lamp-posts, where the escaping vapours can neither give offence, nor prove dangerous. This remedy has been in course of application at Wimbledon during the past five years, and the author hopes that before long there will not be a single sewer ventilator at the street level in the district.

The sum expended by the Local Board on the main drainage works now amounts to 60,000*l.* The sewer rate in respect of the payment of capital and interest on this sum, together with the incidental costs of flushing, &c., amounts to sixpence in the pound per annum. In addition, several thousands of pounds have been expended by land-owners in developing their properties, and the total length of surface drains and sewers now under the control of the Board exceeds 70 miles.

The main pumping station is situated at the sewage disposal works. It contains a pair of high-pressure horizontal condensing engines, with cylinders 14 inches in diameter, and a stroke of 3 feet, indicating 16 horse-power when working at their normal rate of speed. These engines operate a pair of single-acting ram-forcing pumps, each pump having two rams 24 inches in diameter, with a stroke of 4 feet 6 inches. The mean lift is 22 feet, and each pump will lift slightly over 100,000 gallons per hour. Two Lancashire boilers, each 20 feet in length and 6 feet in diameter, supply steam for the pumping and other machinery, the boilers being used alternately for periods of a month.

The sewage disposal works comprise the necessary tanks for the chemical treatment of sewage, and 73 acres of land for its further purification.

There are six settling tanks for the reception of the sewage from the middle- and low-level outfalls, each tank having an area of 50 feet by 49 feet, and a depth sufficient to contain 6 feet of sewage, or about 90,000 gallons. These tanks are arranged to work on either the continuous or separate system, as desired, every tank being provided with a floating arm for the purpose of draining off the clarified sewage from the top in the most approved manner. If desired, the sewage can be passed through the whole series, provision having been made in the division walls for this purpose. As originally designed, there were two tanks only, but as they were constructed with

flat bottoms, the labour of clearing the sludge was very great; the outlets for the clarified sewage were also situated at the bottom in each case, thus allowing the solids to escape.

The two small tanks near the railway which receive the sewage from the high-level outfall are each 30 feet in length by 20 feet in breadth, 8 feet in depth at each end, and 10 feet at the central division, at which point the sewage enters. These tanks are constructed with a false bottom, on which rests 3 feet of burnt ballast, and the sewage is strained upwards through these filters, the solids being left in the space below. A pipe sewer connects these tanks with the large settling tanks, and on opening a valve, the whole of the sewage in the tanks, with the deposited sludge under the false bottom, passes down to the large tanks; this operation being performed about twice weekly. These tanks have given every satisfaction during the ten years they have been in use.

The chemicals used for precipitation are lime and "Spence's" alumino-ferric, or sulphate of alumina in the proportion of 8 grains of the former and 6 of the latter per gallon of sewage. In very hot weather it was found that a slight odour was given off from the land where the treated sewage was subsequently applied, but during the past hot summer much benefit has been derived by the addition to the clarified sewage of 2 to 3 grains per gallon of permanganate of potash.

One of "Scott's" lime-mixers is used for the preparation of the milk of lime, the water used being that from the condensers of the engines. This water is the clarified sewage from the tanks, and, on its temperature being raised, it gives off a slight odour, which is neutralised on passing into the mixer. The milk of lime is conveyed into the pump-well, and in passing through the pumps becomes thoroughly well mixed with the sewage, which is then discharged into a small chamber into which the mid-level outfall discharges; here there is much agitation, and mechanical mixers are not required. The solution of alum is then added, the sewage flows to the tanks, and precipitation of the solids follows in the ordinary way.

The normal flow of the sewage is 750,000 gallons per day; the lime used amounts to $7\frac{1}{2}$ cwts., costing 7*s.* 6*d.*; the sulphate of alumina to $5\frac{3}{4}$ cwts., costing 16*s.*; wages of man, 4*s.*; total, 27*s.* 6*d.* The cost per million gallons would be 35*s.*, the wages of the man being a constant. The sum of 25*l.* may be added to the annual cost for the permanganate of potash used in hot weather.

A small centrifugal pump has recently been added for pumping part of the clarified effluent into the small high-level tanks, so as to provide an additional volume of water for the comparatively large area commanded by these tanks.

The treatment of the sludge has been fully dealt with in the paper by the author, read before the Institution of Civil Engineers (see 'Minutes of the Proceedings,' vol. 88). Briefly, the sludge is swept from the settling tanks into a reservoir, whence it gravitates into the receivers, being then forced into filter presses by air-pressure. There are two of Johnson's presses and one of Manlove, Alliott, & Fryers, the latter being the newer and preferable machine. The following notes may be of use where the adoption of sludge-pressing machinery is contemplated:—

One machine, with twenty-four plates, 36 inches in diameter, will be necessary for 12,000 persons if worked by day only; the air-pressure need not exceed 50 lbs. per square inch, and it should be applied carefully and gradually on recharging each press; care must be taken to use perfectly fresh lime for mixing with the sludge, and strong grey chalk lime, finely ground, will yield by far the best results, the quantity required will be 1 cwt. for each ton of cake produced, if rapid work is to be accomplished, say the filling and clearing of a press in 50 minutes; cakes 2 inches in thickness are produced in the same period of time as those of $1\frac{1}{4}$ inches; flax canvas, costing about $4\frac{3}{4}d.$ per yard, when 40 inches in width, will be the best filtering material, the cloths being made up locally, care being taken to well wet the canvas before it is cut up into lengths, otherwise it will shrink and tear when first used in the presses; the liquor filtered out will be a saturated solution of lime with other constituents, and may best be disposed of by being mixed with the crude sewage, the solids in which it will assist to precipitate, its ratio to the sewage-flow will be about 1 per cent.; the sludge should be pressed whilst in as fresh a condition as possible; the production of sludge cake with about 54 per cent. of moisture will be $2\frac{1}{4}$ tons per week per 1000 persons, very nearly; its value as a manure, if applied as a top dressing as it comes from the presses, will be, weight for weight, slightly in excess of stable manure; the working expenses at Wimbledon now amount to 2*s.* 4*d.* per ton of cake.

The sewage farm, as originally laid out, consisted of 47 acres of land of a stiff clayey nature, having a considerable slope towards the north-east. It was freely under-drained by means of 4-inch glazed socket-pipe drains, laid in contour lines, about 50 feet apart and 6 feet deep, these being crossed at varying angles by larger main drains having a common point of discharge into the river Wandle. The trenches in which the drains were laid, were filled in with burnt ballast to within 2 feet of the surface. On the down-hill side of each of the contour drains, a permanent carrier was constructed of half-pipes with purpose

made stoneware sides, as shown in Doulton's catalogue. The main carriers from the tanks were of cast-iron pipes, and were, and are, a really good feature. It was intended that the land should act as a filtration area, on the principles enunciated by Dr. Frankland; but the futility of carrying out laboratory experiments on a large scale, but under different conditions, was never more strikingly exemplified than in the case under consideration. The land was entirely unsuitable for such a mode of treatment; it was drained not wisely, but too well. The surface of the land was left very uneven, and in many places no sewage could be distributed, whilst in others there was too much—as a consequence the sewage was badly purified, and the crops were very poor, the average prices realised during the first four years being only 190*l.* per annum, or 4*l.* per acre.

In dry weather the land cracked in all directions, giving the sewage direct access to the drains, and the effluent from them was actually worse than before being applied to the land, being laden with masses of sewage fungus. It was also found that the permanent contour-carriers interfered very much with the ordinary methods of cultivation, and, being laid at a dead level, and not being jointed, the greater part of the sewage escaped at the commencement of each carrier.

Such was the state of affairs, when in 1880 Mr. James Snook, who was then engaged with the author in laying out the Merton sewage farm under Mr. Baldwin Latham, was appointed farm manager. Under his management things soon assumed a better shape; all the carriers, except the iron mains, were removed; the burnt ballast under the drains was in great part removed, and puddled clay was substituted, whilst the surface of the land was carefully levelled, and it is only due to the Local Board to say that they spared no expense to render these works as perfect as possible.

One blot, however, remained—the sludge pits, which occupied nearly an acre and were a source of much disagreeable effluvia. These were abolished on the erection of the filter presses by the author in 1884.

Notwithstanding the fact that the land was now in a good condition, the rapidly increasing population—which has nearly doubled in ten years—rendered it necessary to further extend its area. Further purchases of various lands were made, adding an area of 26 acres, 17 acres of which consists of excellent alluvium. This land has been levelled, drained, and prepared for sewage treatment by Mr. Snook and the author conjointly, none of the work having been done by contract.

The utmost care was taken in carrying out the work to avoid the evils pointed out with regard to the original farm, and, with

few exceptions, the only drains laid are those under the centre of each road. The new portion is comprised in the eight plots, situate on the north-east of the point B on the plan.

All the effluent water from the land on the west of Durnsford Road is intercepted at the point A on the plan, and is conveyed in a drain to the point B, where it is reapplied to the surface of one or other of the plots between that point and the permanent contour-carrier farther north. The effluent from the fields between Durnsford Road and the river Wandle is discharged into the contour-carrier at the point C, and is conveyed by means of the carrier to one or more of the plots on its north-eastern side, and is there reapplied as in the former case. Thus the whole of the effluent from the original farm is applied to the surface of the new portion a second time. The result is that the effluent finally discharged into the Wandle is of excellent quality, no sewage fungus having as yet been discovered in the drains of the land recently laid out, nor evidence of sewage contamination in the sluggish branch of the Wandle into which the effluent is discharged.

Three filters of burnt ballast, with an aggregate area of $2\frac{1}{2}$ acres, and with a depth of 3 feet, have been constructed for the purification of the sewage when it is largely diluted with storm-water, but these are rarely used, the land being sufficient for its treatment in case of moderate falls of rain.

In order that the operations described may be better understood, the author has adopted a somewhat diagramatic method in the preparation of the plan. The small subsoil drains on the old farm are altogether omitted, as the mass of detail would have proved very confusing, and the larger ones, only, are shown; the wavy lines indicate the direction in which grips of the ordinary description are cut, rather than their exact position; the flow of the water is in the direction of the arrows.

The crops grown are Italian rye-grass, mangolds, osiers, and vegetables, the areas devoted to each kind being 54, 10, 6, and 3 acres, respectively. Five to six crops of rye-grass are produced yearly, and these are disposed of, as regards the larger portion, in the green state, the principal purchasers being the cow-keepers of the south-west of the metropolis; all not sold is consumed by the Board's horses, either in its green state, or after being made into hay. The average weight of the grass removed from each acre per annum is about 54 tons. The prices obtained vary from 3*d.* to 1*s.* per square rod, on the ground, for each cutting, the grass being mown by an employé of the Board.

The mangolds grown are of excellent quality, the weight produced per acre having last year exceeded 40 tons; these

are sold at from 15*s.* to 25*s.* per ton, in accordance with the ruling prices.

The vegetables are sold at fairly remunerative rates.

Much attention has recently been given to the cultivation of willows and osiers. The willows are readily disposed of to market gardeners, who use them for tying vegetables for the market; whilst the osiers are purchased by basket-makers. The prices now being obtained are about 18*l.* per acre.

The total receipts for produce for the year ending 25th March, 1888, amounted to 1420*l.*, or 20*l.* per acre nearly, as against 4*l.* per acre before the farm was placed under the management of Mr. Snook, whilst the inclusive working expenses were 910*l.*, thus leaving a balance of 510*l.* to assist in the repayment of the interest and principal on the moneys borrowed for the purchase of the land and construction of works.

The costs of the works and land to date are as follow:—

	£
Machinery, buildings, works, &c.	20,866
Seventy-three acres of land	24,432
Draining and laying out original land ..	6,141
Draining and laying out recent purchases ..	2,000
	£53,439

The annual repayment in respect of that sum is 2869*l.*, pumping and maintenance of machinery costs 520*l.* per annum, precipitation of sewage and sludge pressing 811*l.*, or a grand total of 4200*l.*; from this deduct the profit on farm, 510*l.*, and the net annual cost is 3690*l.*, equal to a rate of 6·15*d.* in the pound on the present rateable value, and to 2*s.* 11*d.* per head of the population. It is satisfactory to find that with a rapidly increasing rateable value these rates are gradually growing less.

As regards the future of these works, it is difficult to speak with certainty. The farm is unique, in being within five miles of Westminster Abbey; the growth of the metropolis westwards is increasing at a rapid rate, and already houses are built on the very verge of the farm. With the opening of the new line to Kensington in the near future, a further great development of the eastern portions of the parish is inevitable, and it may be that the time is not very far distant when some other site for the sewage disposal works will have to be sought, or the aid of chemical science invoked, so as to render land treatment of the effluent from the tanks unnecessary. The solution may perhaps be found in a very perfect chemical process, with subsequent filtration of the effluent through small but powerfully active filters. In any case, should the time foreshadowed

arrive, the ratepayers will find themselves the fortunate possessors of an excellent estate of 73 acres, worth probably 1000*l.* per acre, and they will have no cause to regret its acquisition.

The author feels that the paper would be incomplete without some reference to the well-known action of Selous *v.* The Wimbledon Local Board and others, which was tried before Mr. Justice Denman in December 1884. The Croydon Rural Sanitary Authority were co-defendants with this Board in that action. In 1882 the author prepared a paper on the works carried out for that Authority, which may be found in the 'Minutes of the Proceedings' of the Institution of Civil Engineers, vol. lxxvi., which works were one of the causes of the law-suit.

The action was instructive in many respects, and that fact must be the author's excuse for referring to it at some length.

Shortly after the commencement of the working of the Merton sewage farm (described in the paper just mentioned) it was found that the effluent, which passed through Summerstown by means of an old ditch, caused inconvenience by flooding, and it was decided by Mr. Baldwin Latham to construct an independent outfall for the purpose of conveying the effluent from that farm into the Wandle, the outlet being below the old Garratt paper-mills shown in the plan. The point of discharge selected was, unfortunately, but perhaps unavoidably, a bye-wash of the Wandle, which was used for the purpose of relieving that stream from flood waters by means of sluice-gates situated between the bye-wash and the main stream. The rush of water through these gates during floods had in time formed a large deep pool, and it was into this pool that the effluent discharged.

The action, as originally brought, was for interference with this pool in the construction of the works, but in the two years intervening between the filing of the statement of claim and the trial of the action, the grounds of the action were enlarged, and eventually included the pollution of this bye-wash and the air of the neighbourhood, by reason of the operations of the joint defendants. The outfall was brought into use shortly after the original statement of claim was filed, and in the two years intervening between the trial of the action discharged the effluent from the Merton farm into this bye-wash.

Allusion has already been made in this paper to sewage fungus, and this material played an important part in the action. Although frequent analyses of the effluent from the Merton farm showed that it was of excellent quality, it was never free from large quantities of fungus, microscopic examination of which by the author has shown that it is not only

composed largely of the well-known *Beggiatoa alba*, but, as regards a very large proportion, of the beautiful *Vorticelli* and other animalculæ.

It may be mentioned that during the summer preceding the date of the trial of the action the sluice-gates were kept constantly closed, and nearly all the fungus settled in the large pool. On a personal inspection by Mr. Justice Denman, prior to delivering judgment, these gates were opened and the accumulation of months was brought to the surface, and for a short time the bye-wash presented a very filthy appearance.

The following extracts from the judgment itself are interesting:—

"The water which flows into the bye-wash (and here I speak partly from personal observation) contains in it a very large quantity of what is called sewage fungus. The evidence about that substance was interesting and curious. . . . It appears to be a vegetable found in waters which contain sulphur. It was said to be without odour whilst alive, but when dead to be capable of giving off sulphuretted hydrogen, and so becoming foul to the nose. My own observation of what was happening last Tuesday, coupled with the appearances in the Western Pool itself, and the evidence of the witnesses, entirely confirms this account. . . . I have no doubt whatever that that pond, which was proved to have been clear within the last four or five years, and good for perch, has been turned into a very filthy pond mainly by this agency. . . . It is, I think, as plain as anything can be, that a continual discharge, such as I myself saw running into the pond in large quantities, is a 'discharge of sewage or filthy water,' not free from all foul or noxious matters, such as would affect or deteriorate the purity and quality of the water in the bye-wash, but that it has seriously affected and deteriorated it, and must inevitably do so."

The result of the action, so far as the Croydon Rural Sanitary Authority were concerned, was a perpetual injunction to restrain them from polluting this bye-wash, with the imposition of a fine of 200*l.* Special filters were subsequently constructed by that Authority, in order to free the effluent water from sewage fungus.

The Wimbledon Local Board were also fined 200*l.*, and were enjoined so to carry on the management of the portion of the farm adjoining the plaintiff's property, as not to cause a nuisance to the plaintiff. The injunction concludes with this remark: "That they will be able to do this I entertain no doubt, and I may say that if they would always so carry on their works as to produce the condition of things which I observed on Friday last, I think one could not hold them liable to any further proceedings whatever."

With the further improvements and extensions carried out since the date of the injunction, the author thinks that there is small cause to fear further litigation.

The author would conclude by pointing out that the Wandle valley contains three important sewage disposal works—namely, those of the Borough of Croydon at Beddington, the Croydon Rural Sanitary Authority at Merton, and the works herein described. These are three very complete examples of three different methods of sewage disposal: the first-named being that of broad irrigation, the second of intermittent downward filtration, whilst, in the case of the third, chemical precipitation is followed by both intermittent downward filtration and broad irrigation. All may be said to be now working successfully, and their joint effect is to purify the sewage of nearly 150,000 persons; so that the river Wandle, into which all the effluents are discharged, is now one of the purest tributaries of the Thames, and is a bright example to the metropolis through which it flows, and a standing protest to the condition of the mighty—but fallen—Thames, into whose noisome bosom it is received.

DISCUSSION.

The PRESIDENT, in moving a vote of thanks to the author, said that he regarded the paper as valuable, not only because it was a history of completed work, but because the author dealt with the remedy of certain defects which existed at the outset. The extract which the author has given from the proceedings in the action at law were interesting, because they showed the further improvements necessitated thereby, which had since been satisfactorily carried out; but with the legal aspect of the question the meeting had nothing to do. There were many points in the paper which might be profitably discussed, such as the separation of the rainfall from the sewage, the question of ventilation of sewers at the street levels, and the type of sludge presses which had been employed. With regard to the advantage or the disadvantage of the use of lime, the Society would have another opportunity of dealing with that subject at the June meeting, when they would hear a paper upon the Acton Works.

Professor ROBINSON congratulated the author upon bringing before the Society such a clear and interesting account of a very useful work. It was very satisfactory to find that a sewage disposal works, which was originally a cause of trouble and litigation, had been made one of the most successful undertakings which had been brought before them. He would ask

the author for further information with reference to the question of sewer ventilation, as he was not prepared to go so far as to say that the outlets for foul air in the roads should be closed, and that the ventilation of sewers should be solely up houses or up columns in the streets. The openings in the roads should be regarded more as inlets for fresh air, without which the means of carrying off foul air, as the author proposed, would be inefficient, or would not operate successfully. In one part of his paper the author referred to the Wimbledon outfall sewer as a storage when the pumps were not working. He (Professor Robinson) thought it was hardly wise to use a sewer as a storage. It was far better to have a storage chamber at the outfall of the sewerage system, and to collect there any surplus beyond what the pumps were able to deal with. He had been recently engaged in a case in which the use of a sewer for storage had been considered to be the cause of a great deal of sanitary mischief. With reference to a portion of the sewer having fallen by reason of the crushing action of the clay, the suggestion of the author that the pipe sewer should be concreted was quite in accordance with his (the speaker's) own practice. He believed that a great many failures had arisen from the cheese-paring action of those who had designed or carried out works. He would never trust a pipe-sewer with a cement joint without concrete, where there was a possibility of pressure coming upon it.

The cost of 35*s.* per million gallons for chemical treatment appeared to be rather high. The paper did not state what flow per head of the population was treated. He was aware that the exclusion of the bulk of the rain-water caused the sewage to be in a somewhat concentrated form, and if the proportion of fluid per head of population was about 25 or 30 gallons, the case as to cost of treatment would be different, for if concentrated sewage was being treated, his remark as to 35*s.* being high would not apply.

Mr. Crimp said that the normal flow was 30 gallons per head.

Professor Robinson said that his criticism of the 35*s.* per million gallons was based on 40 gallons per head of the population.

With regard to the sludge treatment, there was no doubt that there were no chemical treatment works at the present day which would be tolerated unless the sludge was converted into something like a portable form by artificial means. Where sludge presses were used, the old and well-founded objections to chemical treatment works had entirely disappeared. He hoped that the author would follow up his skilful treatment of the subject, by studying, if possible, the effect of applying sludge

to land. It had been assumed that, because a certain amount of fæcal matter was arrested and converted into portable manure, it would be a benefit to the land as manure. As an old chemical treatment engineer, he had held that opinion for many years, and still wished to do so, but he had certainly been greatly surprised at the want of appreciation on the part of the farmers of chemically treated sludge as a manurial material, offered to them, as it often was, at a merely nominal price; but his observations had led him to consider whether the chemicals arrested the putrefaction of the sludge, and possibly in that way prevented its full action as a manure. If that were the case, it would account for the farmers not obtaining the advantages which had been anticipated from its use as manure, and in that respect the farmer might not be quite so stupid as he had been often thought to be. In thus speaking of sludge he would wish to be understood as referring to the best forms of sludge, which were produced by the minimum of chemicals in proportion to the bulk of the residuum. Experiments were now being conducted with a view of ascertaining the effect of the chemicals on the sludge when it was applied to land, and some results had already been recorded by Dr. Munro. In the construction of artificial filters he had found the advantage of using a little ordinary mould or surface earth on the top layer. He had sometimes converted clayey material by burning into a ballast, and had formed it into a filter, but he had taken care to have layers of alluvial material intermixed with the layers of ballast, the layers being about six inches thick, and the top layer being of some alluvial material. The chemical changes which produced the purification of the effluent or of the sewage took place within the first few feet from the surface, the lower portion of the filter being chiefly for the purpose of arresting suspended matter.

Professor Attfield said that Professor Robinson had taken the usual view, that sewers should be ventilated, but had not given any reason in support of the opinion, and had not drawn any distinction between large sewers, into which men entered, which Mr. Crimp had specially alluded to, and which of course required ventilation for the sake of the men who entered them, and those smaller pipe or other sewers or mains which did not require to be ventilated at all. Of course, if the sewer air had to be taken out of any sewer, it was clear that there must be an inlet for fresh air, so that a continuous current of air might exist. The point was as to either entrance or exit being necessary at all. It was, he considered, quite unnecessary to have ventilating road gratings in suburban districts and provincial towns where the sewers were not large enough for a man to

enter. An idea had existed that the smell of sewage was due to harmful gases generated in the sewage, and it was natural that persons should think that such gases should be got rid of by a current of air, which would dilute them and possibly make them harmless. It was, however, only a matter of assumption that such gases were produced in sewage. It had been found that ordinary sewage did not give off any such gases worth mentioning. The disgusting smell of sewage was due to the vapour of the sewage, just as the pleasant smell of perfume was due to the vapour of the perfume. Neither sewage nor perfume gave off any gases. But it might be said that there were places in sewers where sewage stagnated, and that in such cases the sewage gave off gas. But he (the speaker) had examined a large number of samples of even stagnant liquid sewage, and he had been unable to find that it ever gave off gas. He had also examined samples of sewage sludge which had been left in a sewer when the flow was reduced, and he had been unable to find any gas emanating from it. It was very rarely that bubbles of gas broke away from the solid matters, even of cess-pools, and when any such bubbles appeared, he had found by analysis that they were little else than carburetted and carbonic acid gas, both of which were perfectly harmless. But it had been said that liquid sewage yielded a vast number of micro-organisms which would escape the notice of the chemists, and which might do great mischief. He did not, however, know where there was any evidence that such was the case. Comparatively recently, Drs. Carnelly and Haldane had demonstrated that the air of sewers contained positively fewer micro-organisms than the air outside. He therefore came to the conclusion that sewage did not give off gases or produce microbes, and that there could be no occasion whatever to ventilate, truly ventilate, pipe drains and small sewers. He ventured to ask sanitary engineers and medical officers of health, not for opinions, but for reasons why small sewers, into which men never entered, should be ventilated. In his view such ventilation was a huge sanitary blunder. It seemed clear to him that if they adopted means for drawing air through sewers, all they did was to charge the air with the vapour of the sewage, and therefore they would never get true ventilation. As fresh air was passed in, air which had become more or less laden with sewage vapour was expelled, and the fresh air which was driven in then became charged with the sewage vapour, and this process was continually repeated. In fact, no complete ventilation of the sewers could take place until all the sewage was driven out and there was nothing left but the dry pipes. But some would say that there might be undue pressure inside

small sewers, and that such pressure might force the water seals in houses, and that the sewage vapour would get into the houses and prove at least a nuisance, if nothing worse. But he had diligently endeavoured to find a sewer where there was any such pressure, and he had never succeeded in finding one yet. It was conceivable that there might be such pressure. If a large body of flushing water was driven down a sewer there might be some accumulation of pressure in front of it, but he had never yet been able to ascertain that such pressure was sufficient to force the seal of a water-closet in a house. If there was such pressure, surely men like the author of the paper would know of it. However, he would say, if the pressure existed, then let a few pipes which would act as vents be inserted, but let them be in very few places as compared with the present number of sewer gratings in streets, and let them end overhead. If he might conclude his few remarks with a formula, he would say that, wherever it was necessary, they should have vents, but that in small sewers they should never have ventilation. Vent, not ventilation, should, he would submit, be their guiding principle.

Mr. Rogers Field said that, as to ventilation of sewers, he quite agreed with Professor Robinson, and thought that there was still a great deal to learn on the subject, and that any careful inquiries which were made were sure to do good. He was, however, not prepared to adopt the view that they had all been working in the wrong direction, and that the proper thing was to have no ventilation, but only vent. As far as he could understand, Professor Attfield had taken the view that sewage gave off no gases at all if left alone, but that it gave off certain vapours if air was passed over it. Without being a chemist, and speaking simply from what he perceived by means of his nose, he should disagree with that view. His experience was that, if they had properly constructed sewers, the more ventilation they had the less offensive was the smell which came from them. With well-constructed sewers and proper house-drains, there might be practically no effluvium at all. He thought that it would be a dangerous thing to have unventilated sewers with simply a few vents. He would grant that the pressure was very slight, but pressure certainly did exist at times. All engineers who had studied the subject knew the great variation there was in the amount of water running in the sewers, not only when rain came in, but at different times of the day. At one time there would be a flow of only a few inches at the bottom, and at another time the sewer might be half full. As the liquid came in the air was of course expelled by it, and that air had to go somewhere. He thought that a few small

vents, such as those suggested up the lamp-posts, would not afford sufficient relief to prevent this sewer air from being forced in the houses and through traps. He should regard it as a risky thing to adopt the view of the last speaker without very thorough investigation and trial. The only large town which he knew in which the sewers were purposely left unventilated was Bristol, and what he had heard as to the effect on the house drainage there was not favourable. He thought that the use of the ball for removing the deposits was an exceedingly interesting thing. He had tried a similar ball through an inverted siphon with success, and a ball had been used for a great many years at Paris, where the sewers were carried under the Seine by an inverted siphon. With reference to the reapplication of sewage from clayey land, he considered it a very good plan, and had recommended it himself. Trouble had often arisen in sewage farms where there was stiff clay, and he thought it might be obviated by reapplying the effluent to land which was either naturally porous or artificially made so.

Mr. J. Wallace Peggs congratulated the Society on having acquired such interesting information as the paper contained from such a practical source. He also congratulated the author on having separated the sewage from the rainfall. In works like that at Wimbledon that separation was a matter of vast importance, for every gallon of sewage had to be lifted. It was important that the pumps should have a constant quantity of work, instead of a variable quantity, which would often be beyond their power; and when the pumps were inadequate to the quantity, the sewage often had to go into the river without being treated in any way, and so it fouled the watercourses. He thought that the question of ventilation was the most important point in the paper. In reference to this matter he entirely agreed with Professor Robinson and Mr. Rogers Field. He regarded the ventilation of sewers in a district like Wimbledon as most important. The aim should be to make inlets at the surface of the road, and to form upcast shafts in various ways, by taking the pipes up buildings and so forth. He had noticed in the Wimbledon district a peculiarly designed lamp-post, terminating in a hood, used for the purpose of forming a ventilator. That system seemed a promising one, but it needed to be worked out in a better way. He had seen the same thing at Slough, where the lamp-posts were made into upcast ventilators, and when the gas was alight the heat possibly helped to do some of the work of ventilating. The evil of ventilating by openings in sewers was very well known to engineers. In an unventilated pipe sewer which he had recently had to open, it

was necessary for large holes to be cut and left open for a day or two to let out the foul air before the work could be done. As the Wimbledon district was likely to be developed very rapidly, the author of the paper would do well to exercise the greatest vigilance upon speculative and other builders with reference to the separation of rainfall from the sewage.

Mr. G. J. SYMONS said that the author had mentioned a heavy thunderstorm rain. Falls of three or four inches of rain within twenty-four hours were very rare, but when they did occur the whole was often crowded into an hour or two. There was no instance on record of such torrential falls occurring twice in the same locality. Until the last few years it was usual to make rain-gauges which would only hold two inches and a half, and the result was that when an extraordinary rainfall took place the gauge overflowed and the observation was lost. He had made observations on one such rainfall at his own house in the north of London. He took the record every half-minute, and all the details of the storm were carefully noted, 3·28 inches falling in 56 minutes; but at the New River Head, which was only about a mile from his house, the fall during the same storm was only half an inch. The whole storm was not more than a mile or a mile and a half in diameter. He suspected that the Wimbledon fall was very local. The only other case on record of a similarly heavy fall occurred in the south-west of London, namely, at Camberwell. In that case Dollond, the celebrated optician, measured a fall at his own residence by an instrument which he had constructed, and he found that in two hours the total fall was 3·12 inches. So far as was known, storms which yielded 3 or 4 inches of rain never extended over a large area. They were purely thunderstorm rains, and they belonged to an altogether different category from the heavy rains which prevailed over large areas. He could not help thinking that, from an engineering point of view, as well as from a purely meteorological one, it would be very desirable to set up self-recording rain-gauges. A French firm had brought out a self-recording rain-gauge which worked very well. One had been set up at West Bromwich, and another at Hornsey, by the Local Board. The instrument showed both how much rain fell, and how it fell. Such an instrument could be got for 20*l.*, instead of costing 60*l.* or 70*l.* as formerly. He hoped that engineers would bring a little pressure on their Local Boards to set up these instruments. With reference to the cleansing action of the ball in the sewer, he remembered making an inspection of the Torquay Water Works some years ago, during the Exeter meeting of the British Association. It was shown that the main was very liable to become coated with lime, and a sort of

scraping arrangement* was sent down to clean it out. He should have thought that something of that sort was preferable to a sphere which might be liable to get blocked.

Mr. G. Chatterton said that, having been a member of the Wimbledon Local Board for over seven years, he had taken a great interest in the works which Mr. Crimp had described, and it had been his pleasure to propose at the Board almost every portion of the recent works. With regard to the sewers in the original scheme, Mr. Crimp had mentioned the sizes and the inclinations. The inclinations spoke for themselves. A great portion of the works, as originally carried out at Wimbledon, was just the sort of thing which engineers ought to avoid. To his mind the whole system of the low-level outfall sewer was entirely wrong. In order to escape 20 feet of extra pumping, they had inclinations of 1 in 2300, and in 15-inch pipes there were inclinations of 1 in 1800. He should like to correct one expression which had been made use of by Mr. Rogers Field and Mr. Wallace Peggs. The Wimbledon Board was not closing up the street ventilators unless they found an equivalent means of ventilation, where the outlet would not be offensive. The smells from some of the open grids in the street were awful to describe. Professor Attfield seemed to think that the effluvium was not a gas but a vapour. He should like to know what the contents of the vapour were. Some of the grids were well known all over the parish, and nurses were not allowed to take children within a hundred yards of them. Mr. Crimp had now got rid of these places. Those peculiar looking lamps which Mr. Wallace Peggs had mentioned were not æsthetic in appearance, but still he believed that they were efficacious. When Mr. Snook first became the manager of the sewage farm, the Local Board did not allow him either the necessary money or the necessary labour for what had to be done. When the farm was started ten years ago, it was laid out according to the so-called scientific views of the day, for intermittent downward filtration on stiff clay, and it was the vilest pest place that was ever seen. The sewage was never purified at all. He entreated the Local Board for a long time to do something, but they would not, and during some very hot weather in July 1881, he invited the members to go down to the farm and examine the thing for themselves. A Committee Meeting was held at the place, and Mr. Snook turned on the sewage to the clay land. At that time there were no precipitation works, although such works were supposed to be there. There was a deep well and a wooden stirrer, and nothing more, and he believed that the machinery did not work the stirrer. The

* Brit. Assoc. Report, 1869, sections, p. 210.

sewage used to go over the land and disappear. There was a trench about six feet deep cut in the stiff London clay, and at the bottom of the trench there was a pipe with an open joint, and then there was some burnt ballast on the top. The crops were abominable, and everything stank about the place. As a last resort, they had to use carbolic acid in the tanks, to try to kill the smell. The carbolic acid ruined all the crops. As far as the present sewage disposal works were concerned, he (Mr. Chatterton) would not be afraid if a committee of sanitary engineers were to go and see them. They might find a reason for alterations in many ways, but there was nothing that the Board was ashamed of. The change had been brought about in three different ways. First, the Board had an efficient surveyor. Mr. Crimp had done his part of the work very well indeed. Next they had got a farm bailiff and manager who understood his business thoroughly; and finally the Local Board had learnt that the most economic way of dealing with sewage was to put their hands into their pockets and to give the surveyor and the farm bailiff the money they required. The Board had been mulcted to the extent of 4000*l.* in the costs of the action which had been brought against them; that sum amounted to the whole of the gross receipts of the farm during the ten years that it had been in existence. Thus the whole of the gross receipts of a sewage farm of from 50 to 70 acres were swept away in about twenty-five days in the Courts of Justice. There was not the least probability of their having any difficulty with their neighbours so long as they continued the present system. A great many of the works that were originally put upon the land were now perfectly useless, and represented so much money lost; but the money was not lost, so far as the engineering profession was concerned, because the original Wimbledon works were a very good example of what to avoid. In conclusion, he wished to thank Mr. Crimp for his paper. He was not at all surprised at the ability shown in the paper, because it was exactly what he should have expected from Mr. Crimp.

Mr. Snook, farm manager of the Wimbledon Sewage Disposal Works, said that the best known means were used, and no expense spared to thoroughly purify the sewage. As the effluent went out of the outlet, it was as clear and pure in appearance as anything that could be seen. The alterations made since he had been in charge entirely prevented the sewage from going directly to the drains as it formerly did. The whole of the effluent from the drains on the higher part of the farm was collected and used again on the lower part. All the drains on the lower part were laid under the roads, as shown by the dotted lines on the plan. This lower part of the farm was of porous material, gravel, and

river deposit, to an average depth of three feet, and about two-thirds of the sewage applied filtered through on the porous bed and found its way to the drains. According to his experience of the past twenty-four years on sewage farms, drains laid in the ordinary agricultural style were a very great mistake for sewage farms. Special drains were required to suit the different lands. He had been on many farms, and on one very lately, where the drains were from three to four feet deep, and the whole of the sewage passed into the drains to come out again lower down in as bad a state as before. Such a farm is in operation within ten miles of London. The filtration areas were, no doubt, fine things on paper, but, in his opinion, no filtration area was complete where the sewage was applied directly upon the drains; filtration and irrigation should be combined. To apply a large quantity of sewage to a plot of land, and compel it by embankments to stagnate until it filters through, must be a mistake, as it clogs the surface and prevents aëration. In his opinion, all subsoil drains should be covered up with a bank or road, so as to prevent direct communication of the sewage with the drains.

Mr. S. Holman said that it had been his pleasure to come into contact with Mr. Crimp sufficiently to be convinced that whatever he took in hand would be thoroughly well done. He was not quite prepared to hear a statement from Professor Attfield that he did not think that ventilation in small sewers was necessary. He happened to live in a district where an epidemic prevailed in the early part of last year, and being a member of the Local Board in the district, of course he came in for the usual share of the complaints of the ratepayers, that the sewage works and sanitary arrangements of the town were defective. About the same time Keeling's gas destructor was brought to his notice, and he went to Epsom and saw it in operation. He took an interest in the apparatus, and thought it was capable of improvement. As a result he had brought the consumption of gas down from 15 feet to 5 feet, and he had brought the cost of the apparatus down in the same ratio. The apparatus had been applied to the ventilation of sewers at Richmond. One of these sewers was most foul. Whether the material with which it was impregnated was gas or vapour, it was most strong and offensive. He assumed that it must be gas, because when the furnace was lighted the flames rose up something like 8 or 9 feet, and at that height from the burner the flame melted the solder which was used in one portion of the ventilator. The ordinary gas would hardly give an inch of flame. Such a result would not have happened in a town where a proper system of ventilation of sewers was carried out. There were many towns in England where very badly ventilated

sewers were constructed. As regards Ealing, they had had three or four of the destructors at work for six or eight months, and the effect had been very manifest over a considerable area around the ventilator. If a sewer was ventilated simply by means of openings in the street, the sewer air was not purified, but was simply carried to a higher level. He contended that they had no right to have such injurious matter cast into the open air in thickly-populated places. He did not believe in pressure in sewers. As Professor Attfield had suggested, the idea was, to a great extent, nonsense. It had been the practice, he believed, with the Local Government Board, when they received complaints of the bad ventilation of sewers in a town or of the offensive odours arising, to tell the Local Board that they must increase the number of ventilators or make more manholes, and allow the sewers to ventilate in a larger number of places. The nuisance, however, could not be got rid of by that means, and annoyance and injury would possibly arise from the discharge of gas in the street. It had occurred to him that the most scientific process was to conduct the gases to a point where they could be discharged and destroyed innocuously. If they could set up such a temperature in the ventilators as would cause a rapid current, the object would be effected. The gas could be discharged at a higher level, and the grids in the street could be closed up so as to cause no offence. He suggested this as the most scientific principle to work upon. It would be much better for houses to be in contact with sewers in which the air was changed, than with sewers in which the air was always foul and stagnant. He should be glad to give the members more detailed information, and to show them an apparatus at work, if they would call upon him at his office.

Dr. ARTHUR ANGELL said that Professor Robinson had made a remark which did credit to his powers of observation, and showed how much thought he had given to the subject. He had suggested the possibility of the antiseptics, which were used for destroying organisms in the sludge, preventing the necessary change of the organic matter into saline compounds when the sludge was applied to the land, and so preventing the land taking up the nutriment contained in the manure. That was a very excellent criticism; but he (Dr. Angell) thought that the antiseptics could not act in the way suggested, as the substances which were used must be of a very soluble character, and they would be swept away by the first shower that fell after the sludge was applied to the field. He did not think that there was any real danger of the antiseptics interfering with the decomposition of the sludge. The reason that sludge had been avoided by farmers was rather

a mechanical one than a chemical one. The sludges contained such a large proportion of lime that they formed concrete masses which were not sufficiently porous to disintegrate easily in the soil. He believed that better sludges were being formed now. He went with Professor Attfield to a certain extent with regard to the ventilation of sewers. Of course the question depended very largely upon the amount of gas evolved by the matter in the sewers. But Professor Attfield had forgotten one little point, and that was that there was a considerable quantity of fæcal matter in the sewage. Every one had observed that fresh fæcal matter would float on the surface of water, whereas, when disintegration took place, the intestinal gases escaped and the fæcal matter sank slowly to the bottom of the water. Therefore it would be unwise to have closed sewers. The gas evolved from the fæcal matter must find its way out sooner or later, and if the sewers were made without ventilation there would be a danger of those gases finding their way into habitations and proving noxious. As to sewer ventilators, every one who had been close to them knew that they stank. While pursuing his business as a chemist he had often received shocks of nausea on passing near the ventilators. All the science in the world would never show that they were not a nuisance. Let ventilators be done away with in the road and be carried higher up, so that the gases which were evolved might escape where they would not be a nuisance. The gases must be allowed to escape in consequence of the pressure in the sewers. He believed that they were limited very largely to the intestinal gases which were entangled with the fæcal matter. These gases are the products of natural inter-intestinal fermentations, which go on after the fæcal matters are voided.

Mr. W. G. Peirce, referring to the sewage works at Richmond, said that he was engineer and manager of the water works, and had very carefully read the report of the surveyor, in which he stated that in one sewer the air was so foul that no man could work in the sewer, but that after the destructor had been fixed and applied, the air became so much improved that it was possible for a man to continue in the sewer for any length of time. He (Mr. Peirce) was not in any way connected with the Richmond sewage works.

Mr. G. R. Strachan promised, with the permission of the President, to send a written communication on the subject of the paper.

Mr. Perry F. Nursey suggested that Mr. Holman should supply a written description of the destructor of which he had spoken, for embodiment in the 'Transactions.'

Mr. Santo Crimp, in replying upon the discussion, said that Professor Robinson had somewhat objected to tank sewers, and he seemed to prefer a storage tank at the end of the outfall sewer. It was obvious that, if a tank were put in that position, it must be made of considerable depth, and the pumping machinery would have to be larger and more powerful than it would need to be otherwise. Most likely the tank would be constructed with a flat bottom, or a very slightly curved bottom, and the solids would settle. This would necessitate that the man should enter the tank every day to clean it out, otherwise a nuisance would result. In tank sewers like the small one which he had constructed at Wimbledon, they did not experience any evil results. All the matters that subsided were brought out by the pumps when they recommenced pumping. This tank had been at work for two years. It was examined last week, and there was not a bucketful of deposit in it. It created no offence of any kind. Mr. Chatterton, as a member of the Local Board, had painted the former system blacker than he (Mr. Crimp) had done. He had shown himself always very ready to assist him (Mr. Crimp). With regard to pipe sewers, he did not for a moment wish to condemn them, for he believed that they were preferable to bricks for small quantities of sewage, or for anything up to 18 inches in diameter. It was a very great mistake to construct large brick sewers to convey small quantities of sewage. As to the use of chemicals, the only way in which the expense could be reduced would be by lessening the quantity used, and, having regard to the past, he should not recommend that the quantity of chemicals should be reduced by one grain per gallon. He did not think that it was necessary to mix mould with the filtering material when the filters were only occasionally used for storm-water, as at Wimbledon. He had constructed filters in the manner suggested by Mr. Robinson in the Wandle Valley Main Drainage Works for ordinary filtration. He agreed with Mr. Symons as to the necessity for fixing self-recording rain-gauges. He hoped that at some time he should be able to have one at Wimbledon.

With regard to the question of sewage sludge as a manure when pressed into cakes, Mr. Crimp did not think that the comparatively small quantity of chemicals used affected the process of putrefaction to any appreciable extent. Professor Munro had very carefully experimented with pressed sludges for three or four years, and he had conclusively proved that the manurial value of the material depended very much on its physical condition when applied to land. When the sludge was dried and powdered, its manurial properties were—in the presence of moisture—rendered at once available. The

experiments made by Mr. Crimp had fully shown the accuracy of Professor Munro's conclusion.

With regard to the ventilation of sewers, he had made continuous observation on the Wimbledon sewers during the past four months, employing sometimes four anemometers, but always two. He was collecting some very curious and unexpected data on the subject, which would be made public in due course, and he would not, therefore, anticipate the proposed paper on the subject. He had, however, proved that in long lengths of sewers provided with a 6-inch pipe only at each end, there was sufficient ventilation to preclude the possibility of the traps of houses being forced. Bristol had been referred to, where it was well known the sewers were unventilated; it was a curious fact that, in the ten years 1870–80, the Registrar-General's returns showed that, with the exception of Brighton, Bristol had the lowest zymotic death-rate of the twenty large towns tabulated. For all that, Mr. Crimp was not prepared to assent to the principle of non-ventilation; he would prefer in the case of small sewers, a few ventilators or vents, placed so as to discharge the foul air high overhead.

CORRESPONDENCE.

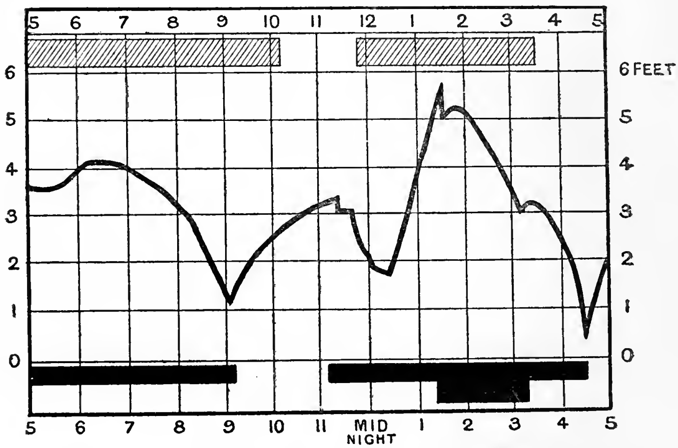
Mr. G. R. Strachan thought that the characteristic feature of the paper was its honesty. So much misstatement had been made about the sewage question that he believed nothing he heard as to it, unless the persons giving the information were personally known to him, only one-tenth of what he read, and one-half of what he saw, and he feared he was too credulous even then. Mr. Crimp had called attention to a pipe sewer failure. He would like to emphasize the fact that the pipe sewer failed because it was improperly laid. In London the fallacy of having sewers large enough for men to enter still obtained, and it might be that those who clung to it would be confirmed in their view by the pipe sewer failure of which they had heard that night. Three years ago the Chelsea Vestry took a division on the question whether a 3 feet 9 inch by 2 feet 6-inch sewer, or a 12-inch pipe, should be laid to drain twelve houses. Last year the Paddington Vestry refused to approve of a pipe sewer for twenty-five houses, and endeavoured to get a large brick sewer laid. On an appeal to the Metropolitan Board of Works, the Vestry were defeated. When it was remembered that a 12-inch pipe sewer, with an inclination of 1 in 400, would discharge 1,000,000 gallons a day, while a 3 feet 9 inch by 2 feet 6 inch sewer, under the same conditions, would

discharge 11,000,000 gallons, and that the cost of the former was one-fourth of the latter, it would be seen how extravagant and unnecessary the big sewers were. The pipe failure at Wimbledon did not condemn pipe sewers, any more than the jerry-builders' failure to build substantial houses condemned the proper use of bricks and mortar.

Mr. Crimp had quoted Punch's merry jingle, "the rainfall to the river and the sewage to the soil," with commendation. It was a catching statement, which, however, did not bear strict application. No one would now take road-water to sewage works, because the volume so obtained was unmanageable, but the question of taking roof-water was in a different position. At Wimbledon some of the rain-water from the roofs was taken to the soil, so that even Mr. Crimp did not strictly apply Punch's rule. Unless a drain to each house was made for rain, separate from the drain for the sewage, the rain-water must, in whole or part, go to the sewage works. So far as he knew, the law did not empower sanitary authorities to compel an owner to lay two drains to his house, and even if that power existed, the advisability of its application was questionable. When he was at Chiswick he kept careful record of the daily flow of sewage, and particularly of rain storms, which proved conclusively the impracticability of dealing with any large portion of the rain-water. The population of the district was 17,000, living in 3000 houses; the dry weather flow of sewage was 482,126 gallons per day, or an average of 335 gallons per minute. The whole of the road rain-water is separated from the sewage, and also the rain-water from the front half of the roof. The rain-water from the back part of the house is admitted into the sewage drains. The area of the district is 1245 acres, and the farthest point of any of the sewers is $2\frac{1}{2}$ miles from the sewage works. The sewage is pumped from the sewer, and an accurate record of the height it stood above the invert was made. On the diagrams the shaded lines represent the rainfall, the black bars represent the working of the engines, and the strong curved line represents the heights of the sewage above the invert. It will be seen on the diagram for the 29th and 30th September, 1883, that at 5 p.m. on the 29th the sewage stood at 3 feet 6 inches above the invert, and the rain commenced at that hour. The engine was started at the same hour, but notwithstanding its power, the height of the sewage rose to 4 feet 2 inches at 6.30 p.m., thus showing that the rain was coming down faster than the power of the engine. As the engine was lifting 1750 gallons per minute, it follows that the rain was reaching the pumping station at the rate of more than five times the average flow. By 9.5 p.m. the engine had lowered the

sewage to 1 foot 4 inches, when it was stopped. The rain-storm continued until 10.10 p.m. At 11.15 p.m. the engine was again started, the sewage being at 3 feet 4 inches, and at 11.50 p.m. it had lowered the sewage to 2 feet 8 inches, when the rain started again. The engine gained on the rain until 12.20 a.m. when the storm evidently came on with intensity, for, notwithstanding the work of the engine, the sewage rose in the sewer

29th and 30th September, 1883.

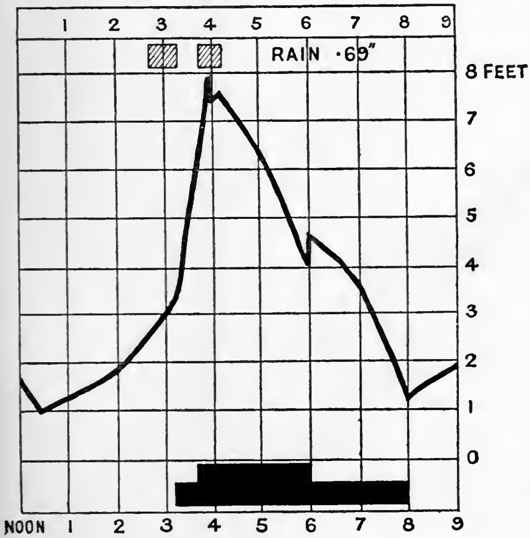


to a height of 5 feet 6 inches by 1.30 a.m. The reserve engine, of the same power, was then brought into work as shown by the lower black bar, and at 3.15 a.m. they had lowered the sewage to 3 feet. The reserve engine was then stopped, and by 4.30 a.m. the single engine had lowered the sewage to 9 inches above the invert. The second rain-storm stopped at 3.25 a.m. At 1 a.m. the sewage and rain was coming down at the rate of 3500 gallons per minute, or more than ten times the average flow. In all 1·01 inch of rain fell, and 1,169,886 gallons were lifted in 12 hours, which was five times the usual volume in dry weather.

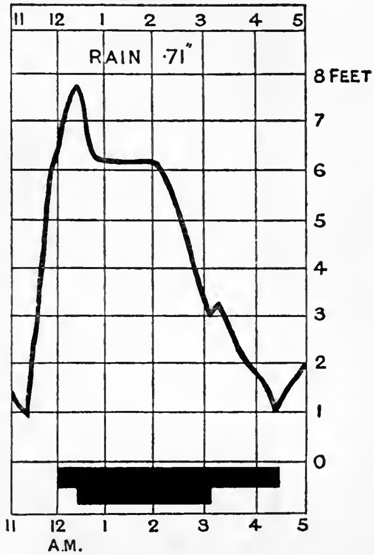
On the 6th July, 1884, a thunderstorm occurred, when ·69 inch of rain fell in one hour and fifteen minutes. The storm commenced at 2.45 p.m. and finished at 4 p.m. At 3.10 p.m. the engine was started, and the height of the sewage was 3 feet 6 inches. The sewage rose against the work of the engine until at 4 p.m. the height was 7 feet 10 inches, when the second engine was started. Both engines worked until 6 p.m. and reduced the sewage to 4 feet 3 inches, when the second engine was stopped, and by 8 p.m. the other engine had

reduced the sewage to 1 foot 3 inches. The volume lifted was 830,227 gallons, which was five times the dry-weather flow for the same hours.

6th July, 1884.



29th April, 1885.



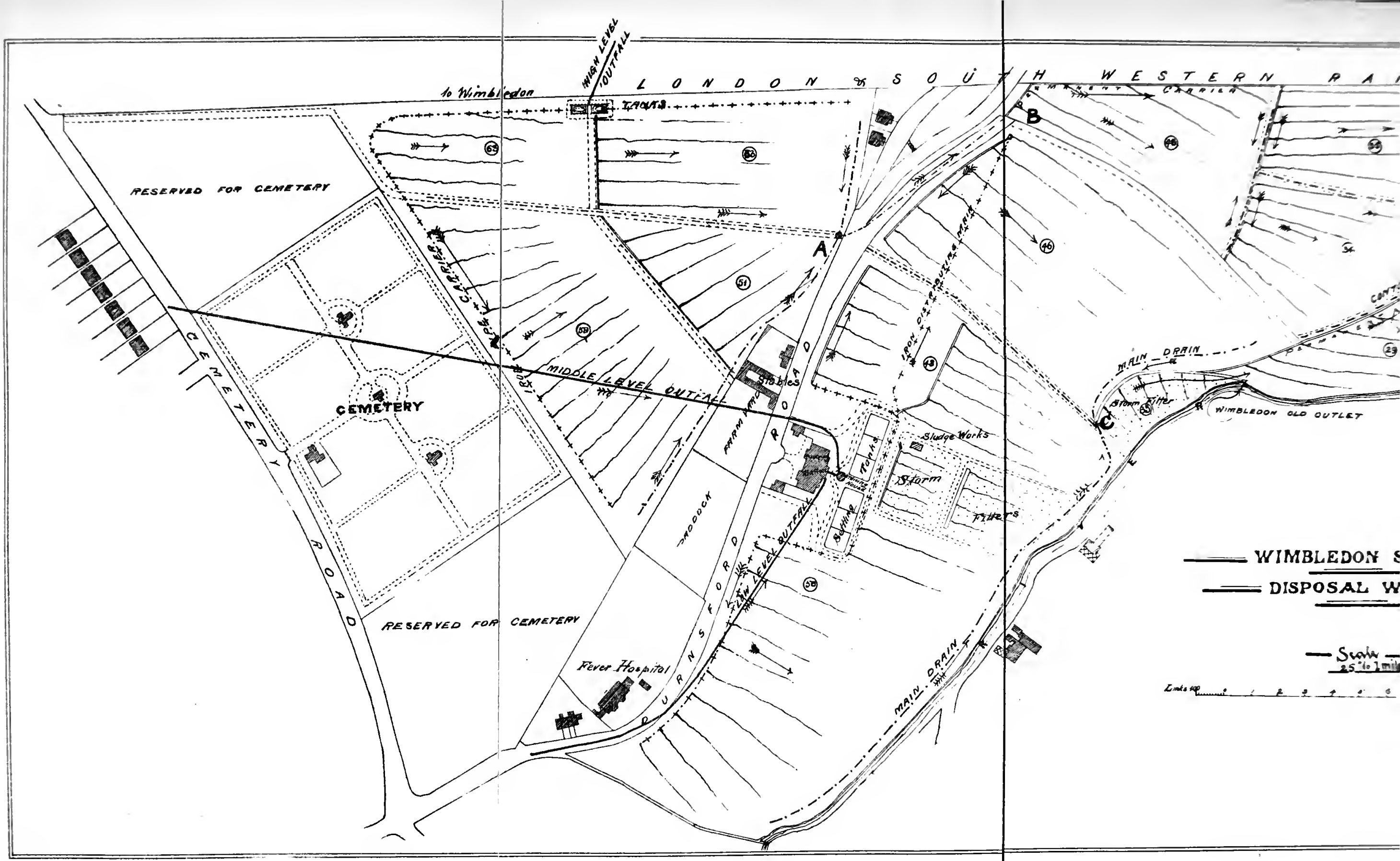
On the 29th April, 1885, a rain-storm of ·71 inch occurred. The times of the rain were not recorded. At 11.15 p.m. on the 28th the sewage stood at 1 foot, and at 12.30 a.m. (one hour fifteeen minutes afterwards) it stood at 7 feet 9 inches. At 12 a.m. one engine was started, and at 12.30 the second engine was also worked. By 1 a.m. they had reduced the sewage to 6 feet 2 inches, but at 2.10 a.m. it still stood at the same level, having maintained its height during those times. From this it is evident that the rain was reaching the works as rapidly as the two engines could lift it, that is, it was coming down at the rate of eleven times the average flow. At 3.10 a.m. the sewage was lowered to 3 feet, when the reserve engine was stopped, and by 4.20 a.m. the other engine had lowered it to 1 foot. In six hours 1,245,510 gallons were lifted, which is ten times the volume of the average flow for the same hours.

These three storms placed the greatest strain on the works, but the following ones show the magnitude of the task of dealing with rain-water. On the 29th January, 1883, ·40 inch of rain fell, and in $3\frac{1}{4}$ hours 528,570 gallons of sewage were lifted, which equals seven times the average. On the 14th

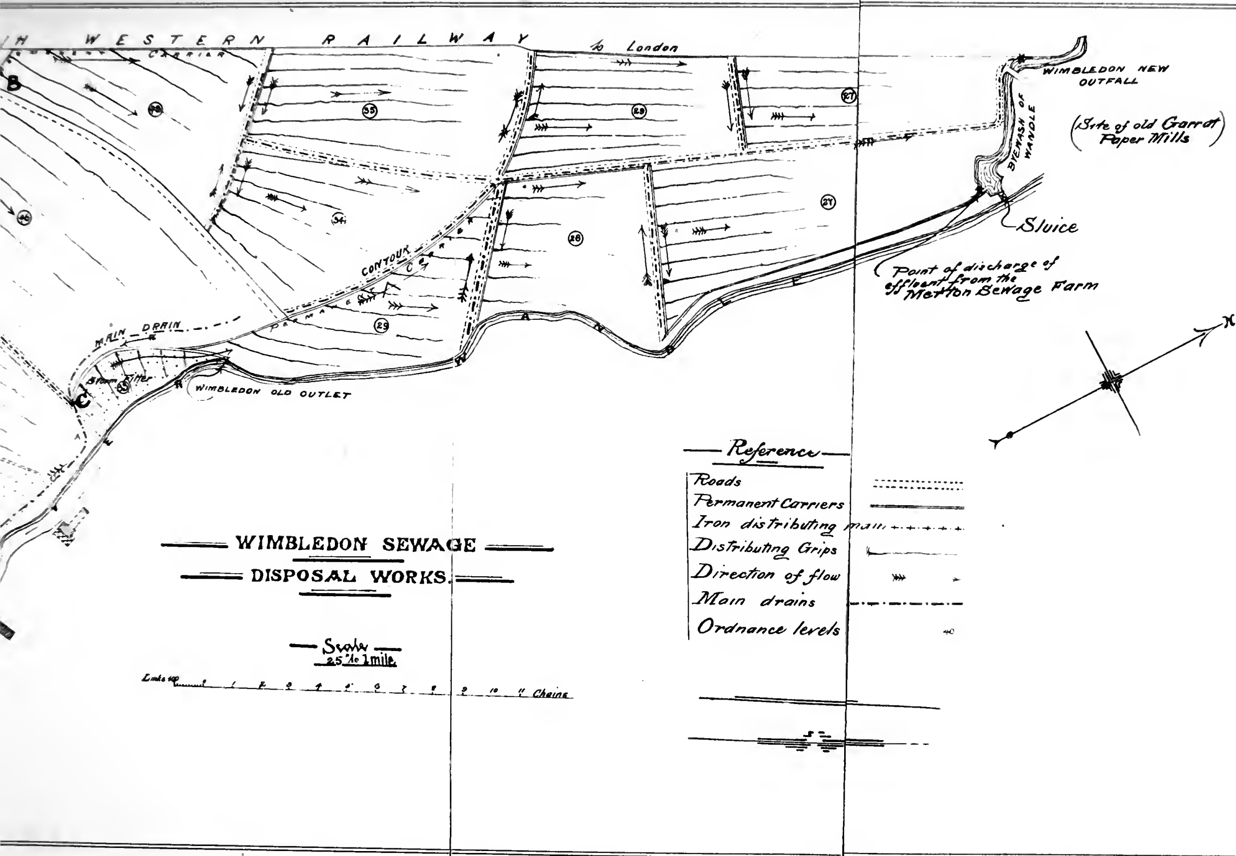
July, 1883, ·55 inch of rain fell, and in 3 hours 361,956 gallons were lifted, which equals six times the average. On the 31st August, 1883, ·55 inch of rain fell, and in $3\frac{1}{2}$ hours 463,243 gallons were lifted, which equals six times the average. On the 26th January, 1884, ·69 inch of rain fell, and in 8 hours 727,284 gallons were lifted, which equals four and a half times the average. On the 1st February, 1884, ·41 inch of rain fell, and in 8 hours 595,950 gallons were lifted, which equals four times the average. On the 11th February, 1884, ·16 inch of rain fell, but the storm was of varying intensity. In 3 hours 536,181 gallons were lifted, which is more than eight times the average. On the 11th March, 1884, ·43 inch of rain fell, and in 8 hours 764,643 gallons were lifted, which is five times the average. On the 7th April, 1884, ·52 inch of rain fell, and 582,437 gallons were lifted in 6 hours, which is five times the average.

The records present discrepancies in the ratio of volume lifted to the amount of rainfall, but this is explained by the fact that only one rain-gauge was used. For instance, on the 11th February, 1884, ·16 inch was recorded by the gauge, but the storm was exceedingly severe not more than one mile away. The fact is brought out, however, in an unmistakable manner, that the rain-water from half the roof area only may send down volumes reaching as high as eleven times the average flow. These figures demonstrate the unmanageable proportions which would be assumed if the whole of the rain-water was taken in, and show that the principle of the rainfall to the river is the only safe one to follow, so far as the bulk of the rain-water is concerned.

With reference to the question of sewer ventilation; when he was at Burton-upon-Trent the sewers were not ventilated, and it was found to be dangerous for men to enter them unless the manhole covers had been off for at least half an hour. The sides of the sewers were covered with a bluish-white slime, and generally the gaseous contents of the sewers were highly offensive. When he was at Chiswick the system of open ventilation at the level of the roadway was rigorously applied. Offence was caused by the escape of foul gases from the open grates, and flushing was regularly and extensively applied at a cost of 600*l.* a year, but the offence, though modified, was not removed. He had come to the conclusion that open ventilation at the level of the roadway was not a complete or satisfactory solution of the problem. The gentlemen who advocated the destruction of sewer gases by burning, omitted to state the cost; but even in London, at the present cheap price of gas, the annual cost of a 5-foot burner would be 5*l.* 3*s.* 11*d.* It would, therefore, seem to be very expensive.



to Wimbledon
HIGH LEVEL OUTFALL
L O N D O N & S O U T H W E S T E R N
TANKS
RESERVED FOR CEMETERY
CEMETERY ROAD
CEMETERY
CARRIER
MIDDLE LEVEL OUTFALL
A
B
C
Stables
FARM ROAD
ROAD
PADDOCK
DURNSFORD ROAD
LOW LEVEL OUTFALL
RESERVED FOR CEMETERY
Fever Hospital
IRON DISTRIBUTING MAIN
Sludge Works
Tanks
Storm
Filters
Settling
MAIN DRAIN
Storm Filter
WIMBLEDON OLD OUTLET
MAIN DRAIN
WIMBLEDON



...H WESTERN RAILWAY
to London
CARRIER
WIMBLEDON NEW OUTFALL
BYEWASH OF WANDLE
(Site of old Garrat Paper Mills)
Sluice
(Point of discharge of effluent from the Merton Sewage Farm
CONTOUR
PERMANENT CARRIER
MAIN DRAIN
Storm Filter
WIMBLEDON OLD OUTLET
WANDLE
B
C
35
29
27
34
28
27
29
N
— Reference —
Roads
Permanent Carriers
Iron distributing main
Distributing Grips
Direction of flow
Main drains
Ordnance levels
WIMBLEDON SEWAGE
DISPOSAL WORKS.
Scale
25" to 1 mile.
Links 100
Chains

In reply to the "correspondence,"

Mr. CRIMP would like to mention that an extensive examination has been made of the 18-inch pipe sewer that had failed, and that the pipes were found to be badly burnt and much too thin. Engineers were now using stoneware pipes the thickness of which was one-tenth of the diameter, an 18-inch pipe would therefore be 1·8 inch in thickness; the pipes that had failed were, however, only $1\frac{1}{4}$ inch in thickness, and, being underburnt and not jointed, had simply been crushed by the clay filled into the trenches. Similar pipes in a sewer 6 feet deep were also subsequently found to be crushed and broken. Obviously the materials were bad, and the construction was bad. Pipe sewers properly designed and laid would certainly meet all reasonable requirements, and should be used for the conveyance of small volumes of sewage. When, however, such sewers are laid at depths of 12 feet and upwards, concrete should be used as an external casing, in order to protect the pipes from crushing. Mr. Crimp thought that the details of rainfall and pumping, submitted by Mr. Strachan, were most valuable. At Wimbledon storm-water overflows allowed excessive volumes of rain-water to escape, but all moderate falls were pumped. The largest quantity yet pumped, due to one fall of rain, was on the 17th of August last, when the volume raised was equal to seven and a half times the normal flow.

Ordinarily, one inch of rain yields 2,000,000 gallons to the sewers, or 70 per cent. of the volume due to the roof area.

Mr. Strachan's explanation of the discrepancies observed with regard to the volumes raised at the Chiswick works, due to storms of rain, is probably the correct one. Mr. Crimp had two rain-gauges in use in Wimbledon, and he had occasionally remarked a difference of 20 per cent. in the amounts recorded, although the gauges were less than two miles apart.

May 7th, 1888.

ARTHUR T. WALMISLEY, President, in the Chair.

FILTRATION BY MACHINERY.

By Edward Perrett, Assoc. M. Inst. C.E.

Of late years the great importance and usefulness of self-contained machines for the continuous filtration of liquids, and especially of water, both for manufacturing and drinking purposes, has been acknowledged; and it is the object of this paper to describe some of the machines which have been brought forward for that purpose, and at the same time to indicate the principles on which the success of such machines depends. It may be as well to state at once that the problem of the re-filtration of already filtered water is a problem which requires little consideration, and the numerous apparatus which are used for that purpose will not be described here; nor will the machines known as filter-presses, as used for the extraction of liquid from a material having an excess of solid matter, or, in other words, for more or less drying such a material; these machines are so much more nearly allied to presses than to filters that they do not come within the scope of the present paper.

It will be as well to state the exact nature of the process known as filtering a liquid, which process should be distinguished from that of straining. To strain a liquid it must be passed through a medium, the passages in which are smaller than any of the particles of matter suspended in the liquid to be strained. On the other hand, the passages through a true filtering medium need not be as small as the smallest particles in suspension in the liquid to be filtered, and yet these particles will be arrested as the liquid passes through the medium, and the effluent will be clear; and for this reason, that the small particles will be attracted in their passage by the greater mass of the substance of which the medium is composed, and will cling to the substance and to one another, allowing the clear liquid to pass on. This attraction of light particles suspended in water by a more solid mass may be well seen by allowing some turbid water to settle in a glass bottle. The sides of the

bottle, although perfectly vertical, will attract the particles near, and when the water is completely settled, some of the matter previously suspended will be found on the sides of the bottle. In fact the filtering action may be regarded as somewhat analogous to that of settling, not by the attraction of the earth, but by the attraction of the filtering medium. This explains, too, the fact that a filter does not act well when the current through it is rapid; for in that case the force of the current acting on the smallest particles is greater than the attraction of the medium, and so these particles are carried through. If the action were one of straining only, it is evident that the rapidity of the current (within reasonable limits) would not affect the action of the medium.

The author first turned his attention to the problem of filtering large quantities of very turbid water in a restricted space, in connection with the floating swimming-bath at Charing Cross, of which he was the engineer; and a short account of the experiments made at that time (although the results, as will be shown, prove that the first systems tried are not adapted to the purpose desired) may be here given, before describing the developments and improvements which have since been made. The first process tried was that which is used in sugar refineries, viz. filtration through bags made of woven cotton. The action of a filter-bag is not in itself that of true filtration, but the cloth acts as a strainer until sufficient strained matter has been deposited on it to form a medium, through which the liquid is then filtered until the mass of deposit becomes impervious. This has always been known to sugar-refiners, and is proved by the fact that a certain quantity of liquid has to pass through a clean bag before the effluent becomes bright.

The bags used for the filtration of the water were from 4 to 6 feet in circumference and 5 to 6 feet long. They were attached at their upper ends to holes in the under side of a tank containing the water to be filtered, the water passing from inside to outside of the bag into a lower tank. The bags were crumpled up so as to be contained each in an external sheath of coarsely woven fabric, of about 18 inches in circumference, so that a large filtering surface was contained in a small space. These bags gave excellent results as regards the quality of the water, but, owing to the imperviousness of the Thames mud, the quantity of water filtered before the bag had to be taken down, and washed by hand, was not great. From a bag having 20 square feet of surface, 50 gallons passed through in five minutes, a succeeding quantity of 50 gallons took nine minutes to filter, and the next 50 gallons took 45 minutes, at the end of

which time the flow was very small. Thus 150 gallons were filtered in the hour, or $7\frac{1}{2}$ gallons per square foot. It was then decided to attempt some more rapid and less laborious method of cleaning. To this end the bags were made open at the bottom, and were attached at their lower ends to holes in the bottom of the lower tank, these holes being controlled by a cock. The filtering process was exactly the same as before, but when the bags were to be cleaned the cock was opened and the unfiltered water from the top tank rushed through the bags, carrying with it the mud which had been deposited during the filtering process. This method was found to answer well for some time, but the action of the current was not sufficiently strong to perfectly cleanse the bags, and so the quantity filtered between each cleansing operation became less and less.

A self-contained filtering machine having cloth for a medium was then devised. It consisted of a vertical perforated drum covered with cloth (Fig. 1), and set so as to revolve, when desired, in an external casing. The water to be filtered is admitted to the annular space between the casing and the cloth-covered drum, and filters to the inside of the drum (not, as with the bags, from the inside to the outside), whence it passes away through the hollow spindle. When it is desired to cleanse the cloth the drum is rapidly revolved, and the centrifugal action, aided by external spray, throws off the deposited matter from the cloth, and in a short time the filter is again fit for work. This filter gives very good results, but owing to the small filtering surface compared to the size of the machine, it is now only applied in cases where it is desired to cleanse water containing matter in a not very fine state of division, which consequently does not clog the cloth very quickly. In fact, this machine as now used, may, according to the definition already given, be classed as a strainer cleaned by centrifugal action. It was found also that for the filtration of water containing matter so impervious as the mud in Thames water, a cloth filter is not the most suitable, and cloth is now used only for water containing matter which, when deposited, forms a pervious mass. The advantage of cloth as a filtering material has been made available in many systems of filtration in connection with Clark's process for softening water. These systems will be referred to further on; but here, before proceeding to mention the machines which are now used for the filtration of dirty water for subsequent manufacturing or drinking purposes, it may be noted that, although it would seem from the considerations just set forth that cloth would be one of the least suitable materials for the filtration of sugar (the purpose for

which it was first introduced), yet all efforts to supersede cloth filter-bags in sugar refineries, and to replace them by some form of machine filters having other filtering media, seem to have been not altogether successful. Probably, however, the consideration of the necessity of having a filter which is perfect as a filter outweighs all others, such as its lasting for a short time only and having to be carefully cleaned by hand; while the comparative value of the liquid to be filtered makes the cost of labour involved in this constant hand-washing of less moment than in the case of water, either for manufacturing or drinking purposes, where so expensive a process of cleaning was found by the author to be out of the question.

It can now be understood that for the filtration of water containing in suspension matter which, when deposited, is practically impervious, it is desirable to have a thick mass or bed for the filtering medium, as in that case a very great surface is brought into action for the attraction of the particles of matter in the water flowing through the mass, and consequently the filter remains efficient for a comparatively long period. The substances—generally granular substances—which have been found effective as filtering media when used in thick masses are very numerous. The sand filter-beds, still generally used by the water companies, are well known. The obvious objections to them from an economic point of view are, that they take up great space, and that the method of cleaning them, viz. by scraping off the dirty layer of sand and wheeling it away to be washed, is both cumbersome and costly. It may be mentioned here, for the purpose of comparison between sand and other media, that the average rate of filtration through sand beds is about 3 gallons per square foot per hour, the water thus filtered being presumably fit for drinking.

For machine filters various substances have been tried and used, and for each particular quality of water to be filtered that substance is selected which experience has shown to be the most suitable with regard to the requirements of the effluent. The filtering medium being chosen, it is then necessary, in order that a machine may be successful, to apply some means whereby the selected material may be easily cleaned, and cleaned so efficiently that there shall be no diminution in the yield of filtered water in the next period of filtration.

The substance which seems to possess a greater power than any other for extracting suspended matter from a liquid, when that matter is in an infinitely fine state of division, is charcoal; and the problem of determining the exact nature of the action of animal charcoal on clear coloured infusions, whereby some or all of the colour is extracted, is one which cannot be said to

have been solved, and which it is not necessary to discuss here. It is, however, a most interesting as well as useful property, and one which has led many persons to adopt charcoal in some form for the ordinary filtration of turbid liquids; but the very fact of its immense capability for extracting matter in an extremely finely divided state (nay, even absolutely in solution) from the liquid filtered through it, would seem to point to the probability that such matter cannot be extracted from the charcoal by any ordinary method of cleaning; and when it is considered that, for the purpose of keeping the animal charcoal used in the final filtration of sugar in a proper condition, it must be periodically placed in retorts and subjected to a red heat, it is evident that for the filtration of drinking-water this animal charcoal, though sufficiently perfect as a filter, and rendering the water extremely brilliant, may in time, notwithstanding frequent and apparently thorough washing, become impregnated with noxious matter, which will ultimately be carried through the filter during the filtering operation. This can only be avoided by the burning process referred to above, which process will be too expensive if used for water filters.

There are, however, many granular substances, akin in several respects to animal charcoal, which, although without the peculiar powers of that substance, are yet capable of rendering fit for drinking such water as is ordinarily intended for that purpose; but the process which is applied in many filters for cleansing these substances is, in the author's opinion, inadequate to that object, this process being the simple and evident one of allowing a reverse current of water to pass through the filter. From the author's experience he would say that, if the whole of the water which had been filtered were allowed to pass in a reverse current through the filter, the filtering material would not be properly cleansed, and the result of this process is the extremely unsatisfactory one of having to periodically stop the working of the filter and to renew the material.

To overcome this defect the author devised a granular filter, which is shown in Fig. 2. This consists of a closed casing of any convenient shape, in which is a perforated diaphragm or tray carrying the filtering material, the upper surface of the material being some depth below the top cover of the machine, and the intervening space being occupied by a perforated trough. The water filters downwards as shown. The cleaning is effected by closing the inlet, leaving the machine full of water, and then passing a reverse current, not of water, but of compressed air, through the material, thus violently agitating it, and by the attrition of the particles loosening the dirt, so that a small current of water causes it to be washed away. In

an installation of these filters for waterworks in South America, where 20,000 gallons of river water are filtered per hour, the space covered is 37 feet by 7 feet 6 inches, the filters being square on plan. This gives an average rate of filtration of about 100 gallons per square foot per hour. The compressed air is produced either by a compressing pump or by an injector, somewhat similar to those used for obtaining forced draught for steam-boilers. The filtering material in this case is retort coke broken to a suitable size, and this material is in many cases very efficacious for the filtration of drinking-water.

In connection with the filtration of drinking-water, the system of purification by iron may be mentioned, although as now practised it is not strictly speaking a process of filtration, but rather a preliminary chemical treatment of the water; the system, however, as perfected by the introduction of Mr. William Anderson's "Revolver," has been very successfully applied, and a short description of the principle and application of that machine may not be out of place in this paper.

The purification of water by contact with iron was proposed many years ago, but more lately Mr. Bischoff produced "spongy" iron, made by reducing hæmatite ore at a low temperature, and this material was found to possess a remarkable power of causing the destruction of any organic matter contained in water with which it was brought in contact. The theory of its action is, briefly, that the iron by contact with the oxygen in the water becomes oxidised, but at the moment of oxidation the organic matter in the water takes this oxygen, thus at the same time partly deoxidising the iron and becoming itself oxidised. The method employed by Professor Bischoff, to use on a large scale the spongy iron which he had introduced, was to pass the water through a filter-bed consisting of a mixture of spongy iron and gravel, 3 feet deep, and covered with a layer of fine filter sand, 2 feet deep, and in this form the filter-beds of the Antwerp waterworks were originally used. Two defects, however, became apparent with the system thus worked: first, as a contact of three-quarters of an hour was said to be necessary for the complete destruction of organic matter, the rate of filtration was very slow, and the area required was consequently very large; and second, the upper surface of the mixture of spongy iron and gravel was found to harden into a crust, which became covered with a slimy matter, so that it was necessary to periodically disturb the bed, and loosen this surface and wash away the deposit. Experiments had, however, been made, both by the late Professor Way and by Mr. Ogston, A.I.C.E., which showed that ordinary iron in a finely divided state, if allowed to fall through the water to be purified, produced equally bene-

ficial results; and not only that, but also the necessary period of contact with the iron unmixed with gravel was found to be one-twelfth of that required in the original process. Mr. Anderson then devised his "Revolver," which is a machine for causing the water to be agitated with a small quantity of cast-iron borings, this form of iron being found to be the most efficacious of any that were tried.

Fig. 3 shows the system as arranged by Messrs. Easton and Anderson at Dordrecht, where the apparatus deals with 1,400,000 gallons per 24 hours. The water from the river is pumped into a small service tank (where any air which may be carried over with it escapes) and descends to the revolving purifier. This consists of a horizontal hollow wrought-iron cylinder, supported on hollow trunnions, on which it is caused to revolve at the rate of about one-third of a revolution per minute. The inlet pipe from the service tank and the outlet pipe pass through stuffing-boxes in the trunnions, and the inside of the cylinder is fitted with curved shelves or ledges, by means of which the iron borings or cuttings are perpetually scooped up, and showered down through the mass of water which is making its way slowly through the cylinder, and in addition there are certain contrivances to ensure a regular distribution of the iron, and to prevent its being carried out of the cylinder by the current, the speed of which is a little under one foot per second. The water after leaving the cylinder rises to another small tank, whence it flows down into a reaction wheel, by means of which, through a train of wheels, motion is communicated to the revolver. The water from the reaction wheel flows into a trough, passing over a perforated false bottom, under which air is forced by means of a Root's blower (not shown on the figure), which is also driven by the reaction wheel. The perforations permit a stream of air to pass through the water, and by so doing assist in reducing the soluble ferrous oxide FeO to the insoluble ferric oxide Fe_2O_3, which is afterwards separated, with the other suspended matter, by ordinary sand filter-beds, which occupy the position of the former spongy iron beds. Although this treatment is not strictly speaking one of purification of water by filtration, yet the author has thought that the description just given of a very successful application of the remarkable action of iron on water, which he has been enabled by the courtesy of Mr. Anderson to place before the Society, cannot fail to be of interest in connection with the subject of the paper.

A material which has long been known as an effective filtering medium is sponge, which is evidently well adapted for such a purpose, offering, as it does, an enormous surface on which the

liquid may act. The author made a great many experiments, in order to utilise this material in a machine for the filtration of large quantities of muddy river water, to render it fit for feeding boilers and for other manufacturing purposes. The form which he ultimately adopted, and which works very successfully, is shown in Fig. 4. The sponge is contained in a closed vertical cylindrical vessel, and is compressed therein between two perforated plates or diaphragms. The upper diaphragm is fixed, but the lower one is attached to a piston-rod, and forms a piston in the cylindrical casing. The piston-rod is carried upwards through the upper diaphragm and through the cover, and an up-and-down motion is given it when required by any convenient mechanism; the figure shows a direct-acting steam cylinder for this purpose. When the filter is at work the sponge is compressed to about half its ordinary volume, the piston at that time being held at the top of its stroke. The water is admitted to the under side of the piston, and passes upwards through the sponge. When the filter is to be cleansed the supply is stopped, and a wash-out pipe at the bottom of the filter is opened, so that a reverse current passes through the sponge. Power at the same time is applied to cause the piston to rise and fall, thus alternately squeezing and releasing the sponge; and this action is found to be perfectly successful in keeping the sponge in the filter in a clean state. The filtering process is thus practically continuous, as the cleaning process only occupies a few minutes once a day. The siphon-shaped pipe shown in the figure is applied for the purpose of keeping the filter full of water when the cleaning process is going on; the cock at the bottom of the siphon is turned at that time, so that the passage leads from the bottom of the filter to the vertical pipe, and the reverse current having traversed and cleaned the sponge, passes out as shown by the arrows, while the sponge is kept immersed in water. The usual method of connecting this sort of filter is to supply it from a tank placed at some height above it, and to cause the filter to deliver into another tank, situated a few feet below the supply tank. The rate of flow through the filter is thus governed by that difference of head, but at the same time the water in the filter is kept under a pressure due to the height of the tank above it. It may be of interest to mention one installation of these filters in London, viz. that at the pumping-station of the well-known Hydraulic Power Company at Blackfriars, where the Thames water is pumped into the mains at an average rate of 25,000 gallons per hour. The filters are ten in number, each 5 feet in diameter, and are arranged in pairs, so that only one cylinder for motive power is necessary for working the pistons of each

pair. The power used is that of the high-pressure water supplied by the company. The floor space occupied by this range of filters is 33 feet by 8 feet. The average rate of filtration is about 100 gallons per superficial foot per hour.

The introduction of the now well-known Clark's process for the softening of water, has led to the use of machines for the extraction of the carbonate of lime formed in that process. Before describing the details of some of the numerous machines now used for this purpose, it may be briefly stated that the Clark process consists in adding hydrated lime to water containing bicarbonate of lime in solution ("hardness" being in most instances due in great part to the presence of that substance in water). The lime in the added water, and the bicarbonate of lime in the water to be softened, react on one another, and become carbonate of lime or chalk, an insoluble substance. For the removal of sulphate of lime or of magnesia, a solution of caustic soda is added in conjunction with the lime water, but by this treatment, though the lime and magnesia are precipitated as carbonates, there remains sulphate of soda in solution in the water; the presence of this substance, though unobjectionable for most manufacturing purposes, renders the water unfit for drinking. If the water thus treated be allowed to settle, it will become perfectly bright, and will be found to have become "soft." This was the system as used by the late Dr. Clark, when he introduced it about forty years ago, but it is evident that by substituting some form of filtering machine for the settling tanks necessitated by the original process, both space and time may be saved. This is the more so since, as has already been stated, it has been found that the deposited chalk is of a very porous nature, and is, in fact, a material which, perhaps more than any other, forms a filtering medium for itself; consequently it is a material peculiarly easy to extract by filtration. It is evident, too, from these considerations that the material which is especially suitable in this case is the filter-cloth mentioned in the former part of this paper.

The first well-known application of filter-cloth to this purpose of filtering softened water, is that of Mr. J. H. Porter, and it has been extensively used since it was first introduced about twelve years ago. The only part of the arrangement to be described here is the filtering machine. This is an adaptation of the filter-press which had been in use for many years. The machine is shown in Fig. 5, and consists of a series of cast-iron rings and discs placed alternately, and having on their sides lugs, which rest on the two horizontal side tie-bolts forming part of the framing of the machine. Both discs and rings have two holes through their faces, near their outer edges, these

holes forming continuous tubes for the inlet and outlet respectively when the discs and rings are brought together face to face; over each of the rings is placed a piece of filter-cloth which hangs over and covers each side of it, holes being made in the cloths to coincide with the inlet and outlet tubes. A small hole makes a communication in each of the rings between the inlet tube and the interior space of the ring; and similar small holes lead from the faces of the discs, which have suitable channels in them, to the outlet tube. The cloths having been placed on the rings, the whole series of discs and rings is pressed together by an end plate moved by a central screw and hand-wheel, the outer edge of each ring forming a water-tight joint with the outer edges of the adjoining discs, the cloth thus hanging against the faces of the discs. The chalky water passes through the inlet tube to the space between the cloths, and filters through the cloths to the channels on the faces of the discs, by which channels it is led to the outlet tube. When the filtering spaces (which are about one inch in depth) become so filled with the deposited chalk that the flow is considerably reduced, the supply is stopped and the end plate is drawn back. The chalk is then removed, and the cloths are taken out and washed. It is usual to have a range of these machines in duplicate, so that when one machine is stopped for cleaning, the corresponding duplicate machine is set to work. Mr. Porter has kindly given details of an installation of his machines at the Camden Sheds of the London and North-Western Railway, where 7000 gallons are softened and filtered per hour. In this case the filters are four in number, but there are sufficient to allow one and sometimes two to be out of use for cleaning. Each filter has 125 square feet of filtering surface, and requires cleaning about once in 12 hours, in which time it yields about 36,000 gallons. The amount of chalk precipitated amounts to about 22 grains in the gallon; thus the quantity of chalk in each filter at the end of 12 hours amounts to about 1 cwt.

The author had many years ago introduced a cloth filter (it was described at the Institution of Mechanical Engineers in 1875) which was a modification of that shown by Fig. 1, and may here be alluded to as being the precursor of one which he has more recently devised, more especially for the filtration of softened water. The older machine (shown by Fig. 6) was designed principally with a view to gaining in the same space more filtering area than that of the drum-filter (Fig. 1). It consisted of a number of perforated copper discs placed on a vertical hollow spindle. The cloth was made into a long open-ended cylinder or "sleeve," its diameter being that of the outer edge of the discs. This sleeve was drawn over the discs,

and tied in between them with cord. It was found on experiment that the whole area of the cloth was not useful as filtering surface, owing to the puckers formed by drawing it in towards the spindle; in fact, the effective area was not much more than the area of the metal discs; but this method of fixing the cloth was found to be more convenient than any other which could be used if the cloth were cut into discs so as to lie flat. The mode of filtering and of centrifugal cleaning with external spray was the same as that applied to the drum-filter. Experiments on Thames water and various liquids were made, but it was found that the centrifugal action, which cleaned perfectly the cloth near the outer edges of the discs, was not sufficient, with any practicable speed of revolution, to thoroughly clean that part of the cloth which was near the axis, and the result was that the full extent of the increased area of filtering surface could not with continuous working be relied on. Other modes besides that of centrifugal action were tried for cleaning the cloth in position; among them, that of scraping or brushing off the deposited matter. This process, however, was found to scrape or brush the deposit into instead of off the cloth; and after several of these operations, the cloth became nearly waterproof; so this system was promptly abandoned.

In the case of chalky water, however, it was discovered that if the external spray were slightly increased, and the discs turned round slowly merely for the purpose of bringing them entirely under the action of the water, this simple operation washed away the light and porous chalk sufficiently to keep the cloth in a continuously efficient state. The disc-filter has therefore been modified for use with softened water, and one form of this modification is shown on Fig. 7. This is almost identical with the earlier disc-filter, but means are given for rotating it only at a slow rate, and the discs, instead of being hollow and perforated, an expensive form of construction, are made nearly solid and of cast iron, the faces of the discs being roughened into concentric and radial channels to allow the escape of the filtered water. The jets for the external spray are of larger size than before, as they alone, without centrifugal action, effect the cleaning of the cloth.

One other typical method used for the separation of precipitated matter in softened water may be mentioned, as being illustrative of the analogy pointed out at the beginning of this paper between the processes of filtration and settlement. The "purifier" of the system of Messrs. Gaillet and Huet, used in England by the Stanhope Company, is an apparatus for causing the settlement of the solid matter in water flowing in a continuous current. It consists (Fig. 8) of a rectangular casing,

open at the top, containing V-shaped trays placed at an angle of about 45°, and fixed alternately to opposite sides of the casing. The water, entering at the bottom of the vessel, passes at a slow rate upwards between the lowest and second trays, then downwards between the second and third, and so on, the matter settling on the upper surface of each tray, so that by the time the water reaches the outlet at the top of the vessel, all the matter is deposited. The sediment accumulates in the angles at the lower ends of the alternate trays, and is drawn off periodically by cocks in the side of the vessel. In an installation of this system at Messrs. Garton, Hill, and Co.'s works at Battersea, the purifiers are four in number. They are each 7 feet 3 inches by 5 feet 3 inches, and 24 feet high, and contain 56 trays, having an aggregate area of 2200 square feet.

The softened water (which contains about 30 grains of solid matter to the gallon) is made clear at the rate of 8800 gallons per hour.

It would be impossible, in a paper of this length, even to mention all the machines which have been brought forward for the filtration of water and other liquids. The aim of the paper has been, therefore, only to mention some leading facts with regard to filtration, to explain some of the experiments and apparatus which have been tried by the author, and to describe those of the machines which have been brought into successful use, as well as such others as have come under his immediate notice.

DISCUSSION.

The President said that in these days of a demand for pure water, either for domestic purposes or as the effluent from drainage works, a paper which dealt with the process of filtration could hardly be overrated in value. The author had stated at the end of the paper that his object was simply to present leading facts, and to describe certain machines, and this he had done most ably, not only in the paper, but also in the diagrams by which it was illustrated. Mr. Perrett's skill as a mechanical engineer was well known in Westminster and elsewhere. The Society were much indebted to him for the paper, and also to Mr. Reynolds, for reading it to the meeting.

Mr. R. W. Peregrine Birch said that they had heard nothing in the paper about the head which was used in the various machines, or rather with the various filtering materials. Of course the head required was a very important matter. They

ought to have some information as to the relation between the head used and the amount of filtration work done. By this he meant, how many gallons of water were filtered per hour, and how much suspended matter was removed from that water. Another important point was the quantity of dissolved organic matter which was made inorganic or oxidised. In the filtering of water the removal of the suspended matter was not the most important part. The suspended matter could be removed by precipitation. He quite admitted that precipitation was a very cumbersome and costly process. He thought the author's remarks upon the water companies' filtering beds would have been more properly applied to the processes of precipitation; and that the process of precipitation came more into rivalry with the class of filter they were discussing, than did the water companies' filters, which were necessarily much larger, and, he expected, much more perfect. He could not think that a filter which passed 100 gallons an hour per square foot could do the work which was done by the water companies through from four to six feet of sand and gravel, at the rate of some 6 inches an hour. He could not quite agree with the distinction made by the author between straining and filtration. At the rate at which the author used the filters, he would not be able to afford to make his interstices larger than the suspended matters which were to be arrested. The water companies got their materials very fine and used them at a very slow rate. Directly the companies got a greater rate of filtration the water suffered, and the examiners noticed the difference.

Mr. J. W. Wilson, Jun., said that he thought that the Society was to be congratulated upon the practical character of the paper which had been read. It would be an advantage if the author could add thereto some tabulated information as to the different processes which he had mentioned. The author had referred to the Charing Cross baths. He (Mr. Wilson) should like to ask him whether it was a fact that these baths had been used for a considerable length of time by the public with every confidence, until they found that the water, instead of being from time to time entirely renewed, was merely water that had been purified. A statement to that effect had been made to him by an engineer who consulted him on a somewhat kindred matter, and if this were the true state of the case, it showed that the public did not place very great confidence in the power of engineers to filter water for such purposes.

Mr. Perry F. Nursey asked the author what was the material of which the filtering cloth he used was made. A short time since there was brought under his notice a cloth made of coconut fibre, which was being used for filtration under certain

circumstances, and which was found very beneficial both as regarded its efficiency and its cost.

Mr. W. P. Morison said that the author had very naturally referred to experience gained in sugar works, where the question of filtration had been dealt with for ages past. He was surprised to find that it was suggested to filter water by means of bag-filters, which were well known in sugar refineries. He did not think that such a thing would have occurred to a sugar manufacturer. The labour in cleaning the bag-filters was very considerable, as the author had mentioned, and their material was costly. In the illustrations referring to the filtering of water, Fig. 5 showed the Porter-Clark filter-press, which was a form of filter used in sugar works. The sugar syrup was generally forced, with steam or air, through presses which were constructed exactly as shown in the diagram. Steam was usually employed, as there was a great quantity of it always produced in sugar works. The pressure used was about 20 lb. to the square inch. These filters were found to be most efficient and very convenient. When the plates were unscrewed and parted, all the cloths were very accessible for cleaning. The filter-cloths in such presses were made of a kind of gunny bag, or of canvas cloth. If the coconut fibre which Mr. Nursey had referred to could be utilised, there would be an advantage, as that material seemed to be suitable for adoption in countries where the coconut abounded. The labour of working the bag-filters had been found so excessive that the form of filter-press shown in diagram No. 5 had been substituted. He had known the use of filter-bags in sugar works to be very much neglected, in consequence of the trouble which they necessitated. His remarks referred principally to works on sugar plantations, and not to refineries in this country, where more skilled labour could be obtained. Of course the main filtering material in the refineries was animal charcoal, a material which had the splendid property of decolourising, as well as of filtering-out solid impurities. The liquid went into the charcoal filter at the refinery a very dark straw colour, and it ran out colourless as water. The decolourising action of animal charcoal rendered it worth while for refiners to go to the expense of burning the charcoal, though that was a somewhat costly operation, not so much on account of the fuel used, as in the labour entailed in handling the charcoal. This would be quite out of the question in dealing with water, where no advantage was to be obtained from the decolourising action.

Mr. B. E. R. Newlands said the last speaker represented to some extent the experience of manufacturers of sugar. He (Mr. Newlands) represented that of sugar-refiners. The

material used in bag-filters was always twilled cotton. The same might be said as to that used in filter-presses for sugar purposes. The cost of working the bag-filters was not by any means such a heavy item as one would be led to suppose, each bag costing only a farthing to wash and put back in its place, and 36 gallons of sugar liquor could be got through a bag 3 feet in diameter and 6 feet long. In the case of water, the quantity depended entirely upon the impurities which had to be extracted, but probably the quantity would be 100 times as much as of sugar liquor. The Taylor bag-filter did not date back for ages by any means; in fact it was only invented by Taylor in the year 1830, so that the bag-filter process was comparatively modern. He had heard a great deal that evening of animal charcoal as a filter. It ought not to be regarded as a filter in the ordinary sense of the word, and could not be properly used as such except at great cost. Animal charcoal was a decolourising and purifying agent. He had had considerable experience in the various methods which had been used for automatically carrying out Clark's process. First of all he worked for a considerable time on the settlement plan, he then worked with the Le Tellier filter, then with the Porter-Clark filter-press process, and lastly with the Gaillet and Huet or Stanhope apparatus. He must say that Mr. Perrett had not done himself justice that evening in the description of his own apparatus, for he had invented many other kinds of most ingenious filters not mentioned in the paper. He (Mr. Newlands) thought that the mistake of most inventors was that each had propounded one simple remedy according to his own commercial interest. As a matter of fact, the question of the most suitable apparatus depended upon the kind of water which had to be treated. London water would settle out at the rate of about one inch per minute, after having been treated with lime and soda, and in this case almost any form of apparatus would do; for if the precipitate was crystalline, a filter-press answered extremely well, but if the material to be removed was of a gummy nature, a filter-press was of no use whatever. If the process was carried so far as merely to take out the temporary hardness, a crystalline precipitate was generally obtained, which did remarkably well with the filter-press; but when soda was added to remove the permanent hardness, a gummy precipitate was the result, which almost stopped the filtration. He had no doubt that the sponge filter would do remarkably well with London water supplied from the waterworks. Recently he had given an opinion as to water of 48 degrees of hardness, and after making an analysis he had stated that it would cost 9*d*. a thousand gallons to treat. The same water

was sent to different authorities in London, and the first one said that he could treat it for *6d.* a thousand gallons. Comparing the analysis of that firm with his (Mr. Newlands') own, he found that they agreed, but the discrepancy arose in the estimated cost of the soda, the firm having taken the price of the impure commercial, instead of that of pure soda. Another authority proposed to treat the water with a mixture consisting of carbonate of soda, caustic lime, and alum. That was a mixture very well known to persons who took an interest in water purification. It was a mixture such as doctors would call one of "incompatibles," because one chemical would precipitate the other. The carbonate of soda would precipitate the lime as carbonate of lime, and there would be a struggle with the alum. It was said that by the process in question, the water could be purified for $1\frac{1}{2}d.$ a thousand gallons. He had no doubt that if they had gone a little farther they would have got a quotation with a negative amount. His object was to point out the great importance of having a correct analysis made, and a correct deduction made from the analysis. It was not sufficient to know the composition of the water only, for practical experience of the various methods of treating water was needed to decide, for instance, whether it was prudent to treat the water warm or cold, and whether it would be best to employ other chemicals for purifying the water than soda and lime.

Mr. J. E. Hodgkin said that he had only two points to remark upon. The first was in connection with the remarks made by Mr. Birch as to the question whether filtration was really a process of settlement. An answer in the affirmative could, he thought, be readily arrived at by a consideration of the work actually done by the "Torrent" (air-cleaned) filter, which not only effectually disposed of the finest visible particles in dirty water, but also was able to remove the "smudge" formed by particles so small as not to be detected separately by the eye. This was accomplished by a filtering medium, the particles of which all passed through a sieve of ten to the inch, and none passed through a sieve of thirty to the inch. He quite agreed with Mr. Perrett that in passing 100 gallons to the square foot of even muddy Thames water, they could get a perfectly bright and pure effluent. Therefore, he submitted that this was not a question of *straining* out. It must be a question of precipitation, or attraction of the fine particles of the mud to the larger ones of the filtering material. With regard to Mr. Newlands' statement that charcoal was a very poor filtering material, he (Mr. Hodgkin) held that charcoal certainly did filter. It need not be freshly burnt charcoal.

The material would last for years. A bed of charcoal 15 inches thick did form a good filter, from which the results just alluded to were readily obtained. The percentage of loss was quite imperceptible. He did not depend upon it as a decolouriser, but he relied upon it simply as a material which, by whatever process, would remove the solid particles from turbid and cloudy water.

Mr. Birch asked the last speaker whether he could tell him the quantity of suspended matter in the water which the filter could deal with.

Mr. Hodgkin said that the filter would deal with water which was almost like mud, but of course the dirtiest water would be filtered at the slowest rate. In ordinary cases they would have to deal with water containing from 30 to 80 grains of suspended matter.

Mr. Birch asked what the effluent water would be.

Mr. Hodgkin said that the water was perfectly bright as regarded the precipitate. If the water happened to have vegetable organisms in it, of course the germs would remain in the water. These would increase and multiply.

Mr. Newlands said that he had not been alluding to wood charcoal. When he spoke of the use of charcoal for a filtering material, he was alluding to animal charcoal.

Mr. Hodgkin said that he also was alluding to animal charcoal, which, as a filtering medium for removing mechanical impurities, he had found quite satisfactory.

Mr. Wilson asked the author what class of sponge he used, and what was the cost of it.

Mr. T. B. Reynolds replied to the discussion on behalf of the author, the latter being too unwell to reply personally. He said that with regard to the question of the head of water used, and the relation between the head of water and the quality of the filtered water, the matter was a rather difficult one to give information upon. The head of water merely caused a flow of a certain velocity through the filtering medium, and the increase or decrease of this velocity caused the filtering medium to detain less or more of the matter in suspension. With the sponge filter, which was used for filtering very dirty river water for manufacturing purposes, a speed of about 3 inches a minute through the filtering medium would render water which contained from 50 to 60, or even 100, grains of suspended matter per gallon, quite clear enough for manufacturing purposes and for boiler feeding. By supplying the filter from a tank which might be 20 feet above the filter and delivering the water into another tank, say 15 feet above the filter, a certain velocity, due to the difference of level between the tanks, but decreased

by the friction in the pipes, and the resistance of the filtering material, was caused through the filter, and this velocity of current was regulated (generally by wire drawing the inlet and outlet) to suit the required purity of the effluent. The maximum difference of head might be taken to be 5 feet as a rough figure, but it could not be given exactly within an inch or two. It had been suggested that tabular statements showing the results of experiments with the various filters described in the paper would be of interest, but such tables would not really be practically useful. The nature of the impurities varied so much with different waters that such tables could not be applied to the consideration of any other water than that with which the particular experiment was made. The general statements contained in the paper as to the yield of the various filters were therefore sufficient, and the detailed results of any particular experiments would, in all probability, not be obtained with any other water, even though it should contain the same number of grains of solid matter to the gallon. The question as to the difference between the filtering and the straining actions had been to a certain extent answered during the discussion. The theory of filtration as set forth in the paper, viz. that of the attraction of the light floating particles by the more solid mass of the filtering material, was, he believed, the one generally accepted. It had been propounded more than once in discussions by Mr. Thomas Hawkesley, an acknowledged authority on the subject. The author did not intend to convey the idea that filtering consisted purely of this attraction. Of course a filter was of necessity to a certain extent a strainer, so far as concerned any particles in the water larger than the interstices of the filter mass; but there was no doubt that the extraction of the extremely finely divided matter which caused the "cloudiness" in water was due to the attraction above described. With regard to the cost, the question was one which was generally asked at discussions, but as all the filters were trade articles, and there were price-lists published relating to them, the cost had been omitted from the paper, and he did not think that it would add much interest to append these price-lists now. As to the Charing Cross bath, about which a question had been asked, the matter was now rather ancient history. The water in the bath was frequently renewed. A certain quantity of the water was let out at every tide, and a quantity of fresh water added. This, with constant aeration, was found to keep the water in a very good condition. He had never heard any complaints about the water.

Mr. Perrett did not try, nor had he had much experience with the coconut fibre to which Mr. Nursey had referred, and

he could not give him any information about it. When the Charing Cross bath was built, bags were thought to offer a large filtering area in a small space, and were therefore tried. As stated in the paper, it was soon found that the cost of labour in cleaning the bags was too great, and therefore the "blow-through" which was described in the paper was used. The labour of cleaning, however, was not nearly so great as with sugar, which is so impervious that in about ten minutes the filtering action ceases; with Thames water the bags would last perhaps six times as long, but not more. The press used by Mr. Porter had been referred to; this was an adaptation of a press used for sugar and other materials, but the water travelled through the cloth and through the mass of extracted chalk much more easily than it would filter through the materials for which such presses were generally used. The question of charcoal had been argued during the discussion. He did not think that animal charcoal was a good thing to use for a filter; in fact it was stated in the paper that if animal charcoal was used for a filter, organic matter was arrested, which after a time germinated and was carried through during the filtering process. He thought that coke or some material of that kind would make a very good granular filter. It did not possess the extreme power of brightening the water which animal charcoal had, but it was not liable to the objection that growths might take place in it. As to the sponge used in the sponge filter, this consisted of sponge clippings, which were easily obtained in quantity. Such sponge was rough and inexpensive, but it was found to last well. The cost of charging the sponge filter was small compared with the total cost of the machines. Mr. Newlands had been good enough to say that Mr. Perrett had many other plans than those described, for the filtration and precipitation of water. The author had, it is true, tried many means, but he had confined himself to placing before the Society the filters used for river water and for drinking purposes, and describing those machines which had come into successful use; the various apparatus which he had tried for precipitation had not been referred to, but the machine of the Stanhope Company, which had really been at work very successfully in some cases, and would be therefore of more interest to the Society. Other filters designed by Mr. Perrett were, to a certain extent, experimental, and although good results had been obtained from them, he thought that it would be better to limit the paper as far as possible to machines of which the success had been proved.

FIG. 1.

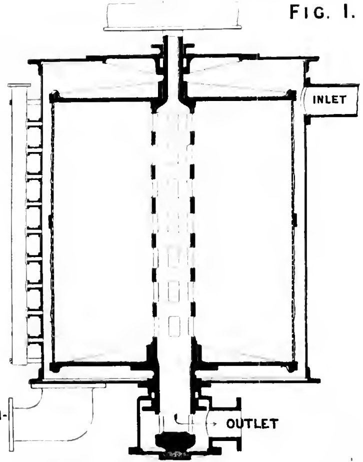


FIG. 2.

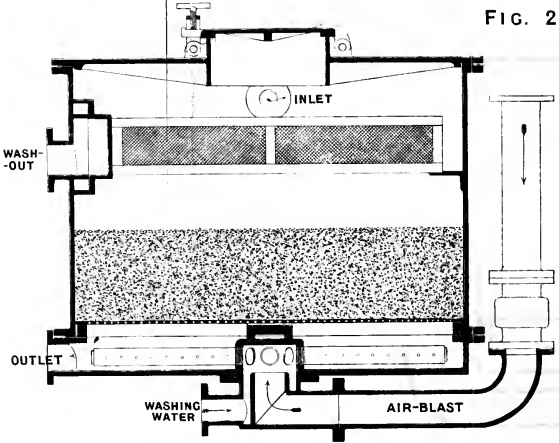


FIG. 4.

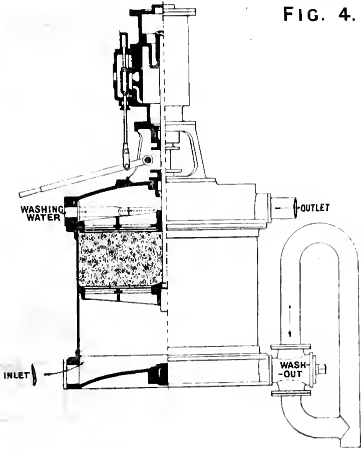


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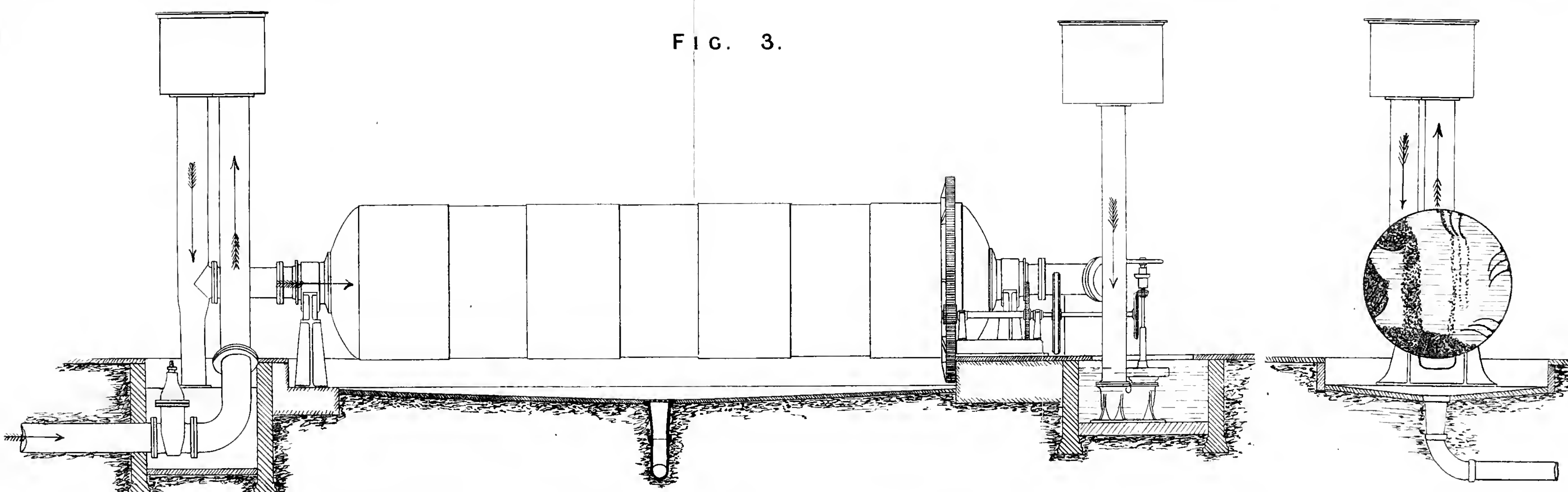
FIG. 3.



E. & F. N. Spon, London & New York.

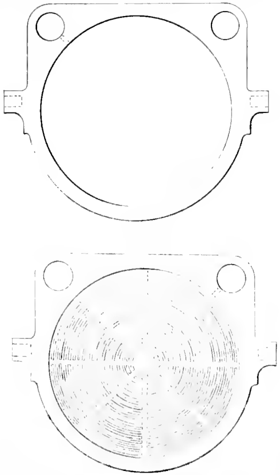


FIG. 5.

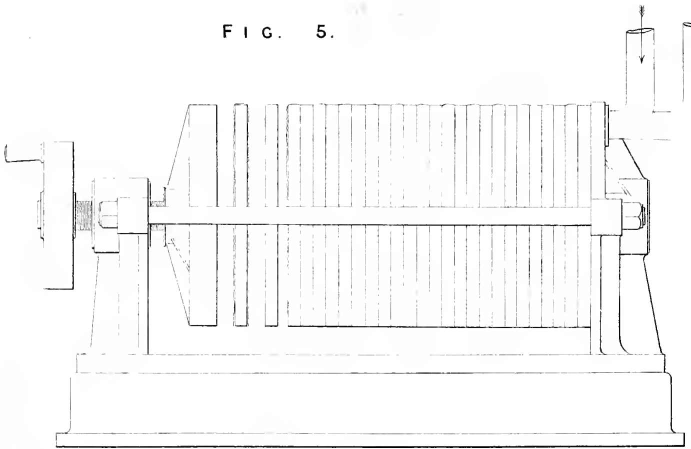


FIG. 6.

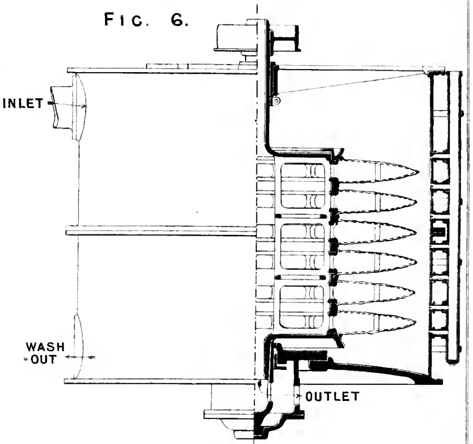


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FIG. 7.

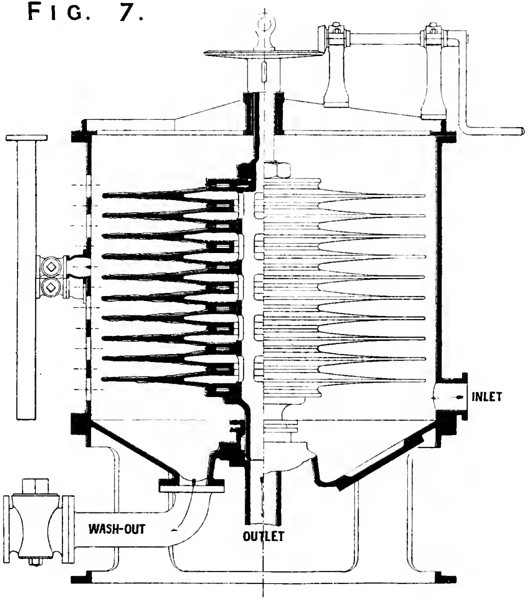
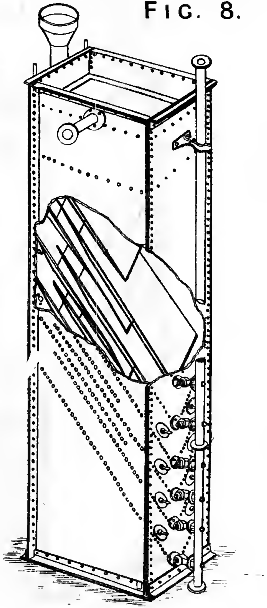


FIG. 8.



E & F.N. Spon, London & New York.

June 4th, 1888.

ARTHUR T. WALMISLEY, President, in the Chair.

THE ACTON MAIN DRAINAGE WORKS.

By C. Nicholson Lailey.

Acton is one of the towns in the valley of the Thames which has carried out an extensive drainage system, thereby rendering the sewage of the district innocuous previous to discharging the effluent water into that once beautiful river.

The district of Acton comprises about 2304 acres, with two watersheds, the East and West Stamford Brooks. Prior to the formation of the Local Board these brooks were open sewers, and received the drainage from the houses then built in the district. The Local Board continued to drain into these sewers, but covered over such portions as were near to the population, until at last almost the whole of the West Stamford Brook was converted into a covered sewer, excepting the portion forming the boundary of the land now occupied by the Chemical Disposal Works, the subject of this paper.

The Metropolitan Board of Works had by this time brought a sewer 5 feet in diameter to the boundary of Hammersmith and Acton districts, which was the Stamford Brook West Branch, and in consequence of the rapid growth and increase of the population in Acton between the years 1866 and 1881, the Metropolitan Board of Works in the latter year instituted legal proceedings against the Acton Local Board, the result being that judgment was given for the plaintiffs, and the defendants were restrained by an injunction of the High Court of Chancery from discharging any further quantity of sewage into either the East or West Stamford Brook sewers.

The population of the district was then 17,000.

The author at this stage was directed by the Board to prepare a scheme for dealing with the drainage of the prospective population, which was in spite of the injunction increasing rapidly, and soon showed the necessity for prompt action on the part of the Local Board. Indignation meetings were held, condemning the action of the Metropolitan Board of Works, for it was maintained by the Acton Local Board that they had

every right to use the ancient outlet for drainage, and that if additional works were required, it was the duty of the Metropolitan Board of Works to construct the same, inasmuch as the ratepayers of Acton had been rated for the construction of sewers then vested in the plaintiffs, and the Stamford Brook sewers had been used by them from time immemorial. A deputation was received by the Metropolitan Board to discuss the subject, but their proposals were met with direct refusal, and accordingly the author was instructed to proceed with his scheme for draining the whole district, in which provision was made for sewage only, leaving the old sewers to remove surface waters. The scheme, therefore, under consideration may be viewed in its entirety as a separate system.

The land chosen for the erection of outfall works is the lowest in the district, being 17·00 above Ordnance datum. It is triangular in shape and contains 5 acres, one side being bounded by the North and South Western Junction Railway, and the remainder by public footpaths. These footpaths extend from the Uxbridge Road to Bedford Park Estate, which is within 150 yards of the site of the outfall works, and on this estate houses of the rental value of from 45*l.* to 120*l.* are built and occupied. The Local Board are also laying out a public park within 300 yards of these works, so that it is self-evident that neither a lime process or a sewage farm could with safety be permitted.

The works comprise—

Precipitation tanks,
Chemical buildings, and
Pumping station.

The district is divided into two sections, high and low level,

The high level comprising 1300 acres
" low level " 1000 "

The sewage from the high-level district arrives at the works through a 3-feet by 2-feet sewer, having its invert level 21·00 above Ordnance datum; and that from the low-level district through a 30-inch sewer, which enters the pumping station 5·0 below Ordnance datum.

Underneath the floor of the pumping station is a storage tank, capable of containing 50,000 gallons of sewage, which the author intends shall be cut off from the main sewer by an automatic valve, and the storage tank ventilated.

The quantity of sewage at present delivered into the works in 24 hours is 150,000 gallons. This quantity is daily increasing as the house connections are made. The point of concentration

is the north-east corner of the precipitation tanks, where it is strained of its coarser particles. It is then mixed with magnetic ferrous carbon, 10 grains per gallon being used. The chemical is first weighed out after this rate and mixed in a mill, which is supplied with water by an inch pipe, when it is brought to a condition to flow freely through an iron channel to a distributing box, from whence it passes out through $1\frac{1}{2}$-inch iron pipes, arranged with cross arms perforated on their under side, in order to treat the sewage with uniformity. In passing from the channels into the tanks the liquid flows on to a platform, which is constructed to rise and fall automatically. By this arrangement it is delivered gently and with little disturbance to the sewage already in the tanks, so that precipitation takes place very rapidly.

There are five tanks in all, three of which are for precipitation, capable of containing 138,000 gallons each, one tank in which is constructed a filter-bed of magnetic spongy carbon, and a reserve tank, in which will hereafter be constructed a similar filter-bed. These tanks are built with Brindle bricks and Portland cement, and although the work was proceeding during very wintry weather the walls are thoroughly watertight.

The amount of chemicals used for the treatment of 150,000 gallons of sewage at the rate of 10 grains per gallon is 1 cwt. 84 lb., which costs 4*s.* per day.

The sludge, or precipitated matter, passes from these tanks by gravitation through 15-inch stoneware pipes into a sludge tank, from whence it is pumped into an agitator, where it is further mixed with pressing powder, before passing on to the presses. The admixture of this powder causes a further subsidence of the sludge, and a large quantity of supernatant water is then drained off, when the sludge gravitates into the press room and is pumped direct by a duplex engine into the presses.

The filter presses are two in number, of the "Drake-Muirhead" patent type. They are of massive design, each having thirty chambers, or cells, of 36-inch internal diameter, in which the sludge is pressed into cakes $1\frac{3}{8}$ inch in thickness. The cells are formed by cast-iron frames, alternated with iron plates, covered with specially prepared mats of coir fibre, which forms, in conjunction with some porous substance, the filtering medium. The mats are securely attached to the plates, and do not require to be exchanged or removed therefrom until entirely worn out. The quantity of wet sludge produced per week is 18 tons, which is pressed into 4 tons 10 cwt. of cake without the use of lime.

A remarkable feature in connection with this process is that

the mineral matter, such as precipitated by the lime process, is to a large extent absent; consequently a richer sludge is produced, and the heavy expense of having to deal with a large amount of practically useless lime sludge is avoided.

Each tank is cleansed (immediately after the removal of sludge), and properly washed down. To facilitate this, water is laid on along the coping walls of the tanks.

The cost of sludge pressing is 4*s.* 1*d.* per ton, viz.:—

	s.	*d.*
Wages for man, $2\frac{1}{2}$ hours, at 5*d.*	1	$0\frac{1}{2}$
" boy, " " 2*d.*	0	5
$1\frac{1}{2}$ cwt. of fuel, at 9*d.*	1	$1\frac{1}{2}$
1 cwt. of pressing powder, at 25*s.* ton	1	3
Oil and waste	0	3
	4	1

These figures may appear unusually high for pressing, but it must be remembered that, by dealing with the sludge without using lime, the author obtains a cake of a considerably higher manurial value, which far more than recoups the additional cost of time and labour.

In the construction of the low-level works, about 8 miles of sewers have been laid, under exceptionally trying circumstances. The soil passed through was full of water, which necessitated a very large quantity of timber being buried, inasmuch as the streets passed through had already been sewered in addition to being lined with houses on each side. The main sewers were constructed of brick and concrete, with a collar joint as an intermediate remedy for keeping back subsoil water. Whilst the low-level sewers were being constructed, it was found necessary, in order to cope with the large quantity of subsoil water, to use a 15-inch subsoil drain, which ran full bore, and three steam engines of 20 horse-power were continually working night and day.

Where stoneware pipes were used, they were laid in a bed of concrete, whatever their size, and concreted three-parts of the way up the pipe, in order to stand the pressure put upon them. The joints were made with tarred gaskin and cement, excepting where in a waterlogged soil; then Hassal's as also Doulton's patent joints were used, both of which proved most satisfactory, and gave without doubt an absolutely watertight sewer.

Doulton's self-adjusting joint is an artificial bored and turned joint, formed by means of casting on the spigot and in the socket of the pipes accurately formed bands of composition. The pipes are supplied with this joint attached, and on arrival at the works have only to be fitted together, no cement or other similar material being requisite. Owing to the accurate fit of the joint,

some lubricant is necessary in putting the pipes together. The casting on the spigot is of a spherical form, and that in the socket perfectly cylindrical. Consequently the joint admits of deflection and withdrawal without leakage. The composition of which the joint is formed, the author is told, has stood the test of fourteen years without any deterioration, during which period it has been extensively used in Stanford's patent joint. These pipes were laid in a cutting 15 feet deep, with water running the full width, and to a depth of 3 inches in the trench, without a subsoil drain.

All the sewers have been laid in straight lines with self-cleansing gradients, with manholes and ventilators to the street level constructed at every 300 feet apart, and at every change of direction, thus enabling the whole system to be under control; and where tributary sewers were joined to the mains, a drop in the manhole was given in order to assist the flow. Iron flushing flaps have been built in the manholes at intervals in order to flush the sewers.

Eight months have passed since the Society of Engineers visited the Acton Drainage Works, and it was remarked by the then President (Professor Henry Robinson), that the working of the magnetic process of sewage purification was in its infancy. During this time the treatment has been carried on in precisely the same manner as then shown to the Society, proving to the author that the process is a very satisfactory one, inasmuch as

1. The effluent is not spoilt by the use of lime.
2. The manurial value of the sludge is much increased.
3. The nuisance (which is witnessed at some sewage works in the kingdom where lime is used) is not created.
4. The Thames is not polluted by it, because the effluent is of great purity.
5. And lastly the cost of manipulation compared with the relative value of the sludge, will bear a favourable comparison with any other process.

The Acton Local Board have entered into a contract with the International Water and Sewage Purification Company to supply the precipitant known as magnetic ferrous carbon, for purifying the sewage of their district, for a term of five years. The process was introduced to the Local Board by their chairman, Mr. W. Roebuck, who is a Member of the Society of Engineers.

Previous to this contract being sealed, the Company were allowed to carry on a series of experiments at the outfall, which they did from November 1886 to August 1887. But it required some little courage upon the part of the Board and the author, to permit experiments to be made by a company, one part of

whose process consisted in the use of a filter-bed, seeing that filtration through artificial beds had been tried and abandoned as entirely hopeless.

A close examination of this particular process soon satisfied the Board and the author that it can in no way be compared with those methods of filtration which had been tested and found wanting.

Failure has always been brought about by the choking of the filter-beds, and this choking has been caused in two ways: 1st. Sewage containing particles of finely divided flocculent matter (which never falls by subsidence alone, however long the sewage is tanked), has been allowed to flow upon the bed, is caught upon the surface, and if neglected to be removed soon forms a film which is remarkably impervious to moisture. The same thing soon happens on land upon a more extended scale, when it is said to be "sick." 2nd. The want of a suitable purifying material wherewith to construct the filter-bed, which should in a highly-concentrated form possess the power of changing into harmless saline bodies the putrescible matters always present in solution in lime sewage effluents.

Again it was soon discovered that the effluent which had passed through ever so many feet of sand, coke, or ballast, was merely strained from solids, and retained all the original putrefactive soluble matter of the crude sewage. Recourse was therefore in some cases had to the introduction into the filter-bed of artificial or natural forms and carbonaceous substances which would have an oxidising action on the dissolved matters, when a marked improvement on the effluent was obtained. Unfortunately, no material could be found which was sufficiently durable to stand the friction produced by filtration. All the substances very soon silted down, rendered the bed watertight, and absolutely useless.

These serious hindrances to an artificial filter have been avoided at Acton by, first of all, allowing no solids whatever to remain on the filter-bed, and secondly, by using magnetic spongy carbon, a hard but exceedingly absorptive substance containing pores so fine that no solid matter can choke the material, and which will wear as long as sand itself. The cost of magnetic spongy carbon used in the Acton filter was 12*s.* per square yard. This material is a rustless spongy oxide of iron, and the author, after careful investigation, is convinced that it is a very remarkable oxidiser.

The sewage at Acton is treated with chemicals which have the property of forming with the solids in suspension, and with the coagulable dissolved matters, a heavy precipitate which subsides, forming an unusually dense sludge in about 3 hours.

Further than this, the supernatant fluid is charged with ferrous salts, which go on acting chemically upon the remaining dissolved matters, and so far break up the molecular constitution of the albumenoids as to render them easily destroyed by the oxidising powers of the filtering material.

After precipitation has taken place, the effluent is passed on to a powerfully active filter-bed, which filters the effluent after the rate of 2510 gallons per square yard in 24 hours. These figures the author gives after careful observations.

The result is an effluent of a very high standard of purity, free from odour, which will not foam on shaking, and will stand the test of exposure to the sun's rays for any length of time without fermenting in any way.

The author asks the indulgence of the Society for introducing absolutely independent testimony as to purity of the effluent by quoting a remark made by Dr. Jacob, Medical Officer of Health for Surrey, &c., on the occasion of his visiting the Acton Drainage Works for the second time on the 2nd May last. He writes—

"I also visited these works on the 4th of April, when I took away a sample of the effluent water, and upon analysis I found it the purest sewage effluent I have ever seen, and I found it to be far superior to many potable well waters."

This speaks for itself that no lime should be used in precipitation works, as to lime may doubtless be traced the putrescible character of all ordinary sewage effluents. That Acton is the first to produce such gratifying result gives to the Local Board every reason for congratulation, and the author has the greater confidence in taking for his standpoint, "No lime and no land."

The first form of organic life which appears in this effluent is a growth of bright green algæ, and this Dr. Angell says is the best possible indication that the fluid is practically free from sewage matter. Whoever may be about to select a material for the precipitation of sewage, should, the author considers, stipulate that under no circumstances should lime be allowed, for instead of removing organic matter in solution, it by its solvent action actually increases it.

After the sludge is pressed by means of the filter presses it is broken into pieces about the size of one's hand. It is then placed in a chamber which is constructed of brickwork, having a series of trays on which the lumps are distributed. At one end a small coke fire is kept burning, and at the corresponding end is erected a Blackman's fan or propeller, worked by means of the shafting from the press-room, and driven at the rate of 600 revolutions per minute, so that a gentle heat and rapid

draught is constantly maintained, the result being that the sulphurous fumes of the coke fire are sucked, as it were, into and through the trays of sewage cake, rendering the cake friable, so that after a few hours it is removed to a grinding mill, ground into powder, and put up into 2-cwt. bags.

The following is an analysis of the sludge cake by Dr. Angell:

Organic matter, carbon, &c., containing nitrogen equal to 1·88 of the cake	30 0
Chalk	3·5
Insoluble matter, magnetic spongy carbon, sand, and clay ..	63·1
Phosphates	3·4
	100·0

The powder-manure is sold at the price of 30*s.* per ton, and the demand is equal to the supply.

Much has been said and volumes have been written on the treatment of sewage on arrival at the outfall works. Thousands of pounds have been spent on such works, and the Local Government Board are approving schemes almost daily, but little care is bestowed in some places on the system of house drainage.

A drainage and sewage system may be well designed and admirably executed, but the result is likely to prove very disappointing if the all-important point of removing the great nuisance from the dwelling is not properly and carefully attended to.

The author is endeavouring to give special attention to the subject of house drainage, and he insists upon the drainage of houses in his district being carried out in accordance with a definite system. Wherever a drain passes underneath a dwelling, it is entirely surrounded with Portland cement, concrete, and ventilated. In some instances excuses are made by the speculative builder, a class which it is to be feared abounds in every district surrounding London, that the inlet pipe for fresh air to the drain will be objected to by his tenants, but this difficulty has been met by the introduction of an air inlet constructed in the fore-court walls. The soil pipes are ventilated by means of 4-inch shafts above the house tops, and proper ventilating air bricks in every closet are insisted upon.

Although not called upon to do so by Act of Parliament or the Bye-laws made under the direction of the Public Health Act of 1875, the author encourages builders in his district to apply for certificates of completion of their dwellings, more especially to show that the sanitary arrangements have been executed according to the law. He also advises that a copy of the plan

of drainage which is made by the building inspector should be supplied to such builder, in order that he may show his intending tenant or purchaser that every possible care has been taken in the design and construction of the sanitary arrangements of the dwelling about to be occupied.

In conclusion, the author desires to place on record, that he believes the success which has attended these works is in a great measure due to the fact that the Local Board, aided by their Chairman, have from the commencement borne in mind that without efficiency no good results would be attained, and he wishes to express his sincere thanks to his Board for the valuable assistance rendered to him in the arduous task he has been called upon to perform.

The works at the outfall, inclusive of machinery, have cost about 15,000*l.*

DISCUSSION.

The President said that this communication was a very valuable one. The Members of the Society had been well impressed with the success of the works at Acton upon the occasion of their visit on the 19th October last year. Professor Robinson, the President for that year, then announced that the scheme was in its infancy, but since that time the hopes of the Local Board had been fully realised, and it was seen that the system was worthy of adoption in other places. The first point to be noticed was the absence of lime in the process of precipitation, and the use of magnetic ferrous carbon. He should ask Dr. Angell, as a chemist, to say something presently on that subject. The absence of lime greatly increased the value of the manurial cake, and this fact, together with the obtaining of a pure effluent under favourable circumstances, strongly recommended the system. The subject was one that might be very profitably discussed.

Dr. Arthur Angell said that it was a common habit of chemists, when they appeared before learned societies of this kind, to fly a very high kite, and to say that they were not interested in any way, except as scientists, in the matter which they were describing. Perhaps he himself would have been more careful in speaking on the present occasion, if it had not been for what he considered the undeniable success of the application of the process described in the paper. He had been acquainted with the material from the time that it was first in the test tube, and he was now proud of the association. He

was extremely thankful to his friend Mr. Lailey for the very able manner in which he had carried the new method on, from the laboratory stage to the stage of practical application. He did not claim that they were discoverers of a new chemical agency. Probably the meeting would look upon him with a considerable amount of suspicion if he stated that he had discovered some new reaction in the treatment of sewage; but what he claimed was, first of all, a combination of precipitation with filtration.

Filtration had been tried previously and had failed. It had failed because solid matter had been permitted to pass upon the bed. An effluent which was allowable in one place was not allowable in another. He maintained that Mr. Lailey's position near the metropolis put the system to the most crucial test. The words of Dr. Jacob pleased him as coming from an outside authority without any invitation, and he (Dr. Angell) would follow those words, and say that the effluent water was shown by analysis to be better than many waters which had been submitted to him for his opinion upon them as drinking waters. Perhaps many persons were still of opinion that land was the most natural way of dealing with sewage. Undoubtedly there was a time when that was the case. In the primæval forest the use of land was a very easy means of getting rid of all the trouble; but at the present time they must make use of artificial applications for doing away with an artificially produced nuisance. For the precipitation, as Mr. Lailey had very distinctly stated, they were using a material which was capable of precipitating, deodorising, and defecating the sewage in the tanks, without the application of that abominable alkaline lime process. That process was abominable, not only in the ordinary acceptation of the term, but also scientifically. If it was desired to throw out the emanations of a putrid substance, so as to tell that ammoniacal compounds were present, it was one of the most elementary lessons in chemistry, that lime should be put to the substance in order to throw out those emanations. If they would only think that out, they would see at once that the use of lime was abominable and to be avoided if possible on all occasions.

He should like to say, by the way, with regard to the filtering material, that they hoped to show that it was capable of dealing even with lime effluent, where for any reason the use of lime was retained. Under such a condition all that would be required would be the laying down of the filtering material. The precipitating agent owed its chemical agency mainly to ferrous sulphate. There was a consensus of opinion that ferrous iron in the form of sulphate was one of the best materials for the

prevention of putrefactive changes in sewage. Of course one of the objects in all treatment of sewage was to prevent putrefaction. It should be taken fresh, and treated as quickly as possible, that it might not pass spontaneously through putrefactive changes, as it would do if left alone. But all sewage, however rank it might be, would ultimately become as pure as it could be made by any artificial process, if they would only give it sufficient time. The only objection was that during the processes there emanated from it those noxious gases which produced a nuisance in the district where the change took place.

Mr. Lailey had told them that the absence of lime had considerably lessened the quantity of sludge and added to its value. He was very pleased to hear Mr. Lailey say that he was selling his sludge at 30*s.* a ton. To his (Dr. Angell's) mind that was quite a good price for that form of manure. The Acton sludge was a very good manure compared with any other which he had had an opportunity of examining, and he had examined a great many. High prices for sludges, even up to 3*l.* or 4*l.* or more a ton, had been quoted by interested parties; but those who had had to do with sewage schemes as long as he had knew that those prices were not based upon reliable information. At the present moment Mr. Lailey had orders for sludge over and above the stock which he had on hand.

With regard to the science of the process, he would simply say that in the tanks the precipitate was added in the way that Mr. Lailey had described, and allowed to stand for about three hours, and then the supernatant liquor, or the tank effluent as they called it, was allowed to pass upon the filter-beds. In two or three hours the tank effluent was somewhat turbid, but contained very little suspended matter. A powerful reaction could be obtained from it for ferrous iron. If iron was present in an active condition at that stage of the process, putrefaction could not take place at ordinary summer temperatures. If there was an excess of ferrous iron in a solution, it was impossible for putrefactive changes to take place; the surplus must be used up by a chemical reaction, in some form or other, and neutralised or precipitated by oxidation, before putrefaction could take place. Therefore, they had been careful in all instances in the early stages of the process to see that they had an excess of iron. Then the tank effluent was passed to the filter-bed, and in practice they had very little difficulty in keeping the filter-bed free.

The process was now running on its own legs, and he seldom visited Acton. This success must be a great gratification to the members of the Board. In the introduction of new processes somebody must take a bold step, and give the innovation

its first trial. It was no good for everybody to wait until somebody else had given the process a trial. The principal constituents of the filter-bed were magnetic oxide of iron, carbide of iron, and silica, with some carbon. Thus they had practically an insoluble substance. That was a very important fact. If the substance was soluble, of course it would be washed away in time, and perhaps in a very short time. A piece of the raw material, which he now had with him, would be found to be a natural rock. It was simply carbonised for use, nothing being added to it in the form of organic or carbonaceous matter. It was left in an extremely porous, open, vescicular form, and it had the power of concentrating atmospheric oxygen upon its surface, and it also had a magnetic power which at present he was not quite able to comprehend; but it certainly had a power upon the water, probably electrolytic, so that it took up a fresh supply of oxygen from the liquid passing through it, and handed that oxygen over to the oxidisable organic matter, and by means of this action the material would be revivified. That was the only theory or hypothesis which he could form to account for the continued action of the filtering material upon the organic matter.

In the case of an effluent produced at Nutfield in Surrey, the sewage was, he believed, passed through an osier-bed, and then through the filtering material; it was found to be odourless and bright and clear in a 3-foot tube. The residue of a quarter of a litre was clean and white, and when ignited scarcely darkened, and gave off no odour of burning organic matter. He would defy any effluent which had been produced by lime to pass through such a test as that. The specimen of Acton sewage effluent which was taken in presence of the ex-President, Professor Robinson, and other members of the Society of Engineers, last year, was found to be bright, clear, and slightly yellow in appearance, as seen in a 3-foot tube. The residue was clean and white, as in the instance he last mentioned. He had brought with him some of the filtering material made from the rocky substance which he had already exhibited. This was brought into a granulated condition for use, and it was very magnetic. It had been through all sorts of tests for the purpose of being made to oxidise; but it was a remarkable fact that, although it contained nearly 37 per cent. of iron (not, of course, in the free condition as metallic iron), yet they were not able to make it oxidise by any ordinary treatment, such as continuous wetting and drying, and so on. This was important, for if it rusted at all the pores would soon be filled up and the material would be useless as a filtrant.

Mr. G. R. STRACHAN said that Dr. Angell had very ably discussed the paper from the chemist's side. Perhaps he (Mr. Strachan) might be allowed to act as a critic from an engineer's standpoint. First of all, that which struck him in the paper was the absence of the detailed information which one usually expected. He noticed that Mr. Lailey, while giving the population of Acton at the time the injunction was obtained against the Board by the Metropolitan Board, had not stated the population now using the sewers. Without such information, one was somewhat at a disadvantage in testing the process by the only way in which it could be tested, namely, the cost and results per head. Mr. Lailey gave data from which one could ordinarily arrive at the population, but these afforded contradictory results. The sewage coming down was stated to be 150,000 gallons a day. 30 gallons per head per day, which was a large estimate for Acton, would give a population of 5000; but the pressed sludge, which was put at 4½ tons per week, would, on the usual basis of calculation, give 2340 persons. Assuming the population of 5000 to be correct, they found that at Acton the sludge when pressed was less than one cwt. per head per year. While speaking of sludge, he should like to express his disappointment that Mr. Lailey should have found the cost of pressing by direct-acting sludge presses to be 4*s.* 1*d.* a ton. That price did not include lime, which, under the ordinary system of pressing by air, was a very large and expensive factor. This meant that the cost of working by direct pressure was greater than by air vessels. He was exceedingly disappointed at this result, because personally, when he saw Messrs. Drake and Muirhead's presses at Maidstone, he formed a high opinion of them. He still thought that direct action was the proper way of pressing sludge, and that the air vessel should, if possible, be done away with. Messrs. Drake and Muirhead being present, he should be glad if they would explain why the cost was 4*s.* 1*d.*, as against the 2*s.* or 2*s.* 6*d.* of the air-pressure system; or if they could not, to give some better hopes for the future. He should like Mr. Lailey to explain what was the object of having such a very deep sludge-well, which would appear to be 36 or 40 feet deep. He thought that the new process had been scarcely worked long enough for them to judge positively as to its results; and the opinions which had been given did not appear, when closely examined, to be so valuable as they seemed on the surface. For instance, let them take Dr. Jacob's remark, that the effluent was superior to many potable well-waters. Some potable well-waters were very poor stuff indeed. He would suggest to Mr. Lailey that the paper would be made

really valuable, if, instead of giving the opinion of Dr. Jacob, he would give the analysis upon which that opinion was formed. They could then compare it with the analyses from other processes. Mr. Lailey further stated that the magnetic carbon filter wore as long as sand. Personally, he (Mr. Strachan) did not know how long sand wore; but he was very anxious to know how long magnetic carbon would wear, and he should therefore like to have some definite statement on the point. He had heard it claimed for magnetic carbon that it was everlasting, but he ventured to doubt that. Then, further, the rate of filtration was utterly astounding. Mr. Lailey had stated it as 2510 gallons per square yard in 24 hours. In waterworks, where the water went through first-class sand filters, 500 gallons per square yard per day was a very good result. He knew that in the Chelsea Waterworks they were perfectly satisfied with 378 gallons, and in the East London Waterworks they did not force the filter up to 500 gallons per square yard per day. But in the paper they had the spongy iron filter doing five times as much as the filters at the waterworks, and doing it better; for they must remember that the waterworks filter took water which was purer than effluent. He should like to be assured that the 2500 gallons per square yard per day could be thoroughly relied upon in consequence of the experiment having extended over a substantial length of time. He noticed that the accommodation of the three tanks came, roughly speaking, to 400,000 gallons, and that each of the two filters, on the basis of 2500 gallons per square yard per day, was large enough to deal with more than the whole of that volume. He should like to know why two such large filters were made, while one was sufficient for the three tanks. He had made these criticisms in all good faith, and having made them he should like to pay a tribute of commendation to Mr. Lailey for the very efficient system of recording house drainage inaugurated at Acton. He thought that the system of giving a certificate from the local surveyor as to the drainage of a house, together with a plan of the drains, was a very excellent one, and he hoped that Mr. Lailey would be able to carry it out on every occasion.

Professor Henry Robinson said that the Society was very much indebted to Mr. Lailey for bringing forward this paper, and for showing how a competent and independent-minded surveyor insists on builders carrying out works of house drainage in a way which was very much needed in this country, and further, that a proper record was required to be kept of the works which were carried out. That builders should be compelled to conform to the most stringent regulations, was, to his

mind, of the greatest possible importance. The works which had been described appeared to have been carried out very successfully under circumstances of no ordinary difficulty and trouble. To those who had to deal with the disposal of sewage, the trouble of subsoil water was often enormous, and required great care in laying the sewers. The pipe joint described by the author appeared to be practically flexible, and if it was used for a sewer which was liable to settlement, such a joint might be productive of much mischief. In making a sewer in bad ground, he should never rely upon a joint which would at all yield to the settlement of the ground. It would be much better to deal with the matter at the outset, and make the sewer perfectly safe by putting in a proper concrete foundation, or by using an iron pipe, whatever the cost might be. With reference to the outfall works, he had occasion to visit them last year as President of the Society. In the few observations which he made upon that occasion, he was very reluctant to express a strong opinion as to the process employed, which was then in its infancy. The various questions which Mr. Strachan had put were very proper ones, and recommended themselves to his (Professor Robinson's) mind most thoroughly, as tending to increase the value of the paper, and no doubt Mr. Lailey would supplement his paper by giving the information which Mr. Strachan had asked for. But, setting those criticisms aside for the moment, what struck him at the time of his visit to the works was they had adopted a process which appeared to remove the impurities in solution in the effluent water in a way which they had hitherto relied upon filtration through land to accomplish. This struck him at the time as being very important to engineers who had to carry out sewage works, and that impression had been confirmed by what he had seen more recently. When the Society visited the works eight months ago, the sewage which was being treated was very dilute indeed, for he believed that only a few of the houses in Acton were then connected with the sewers; but he had seen the works more recently, and on the last occasion the sewage which was being treated was from a large part of the district and was fairly strong. The effect of the precipitating materials employed certainly required further investigation before any opinion worth accepting could be formed. The point, however, which impressed him most was the fact that although the effluent from the tanks (or the supernatant water) was not so clear as effluents from some other systems and contained suspended matter as well as dissolved impurity, nevertheless that effluent after being passed through a few inches of sand (which removed the suspended flocculent matter) passed through the filtering material and became

certainly not only brilliantly clear, but, according to Dr. Angell, was chemically an excellent effluent. The importance of this process to an engineer appeared to him (Professor Robinson) to be that he had now some means of raising the purity of his effluent to a very much higher standard than he ever had before in a limited area. Whereas the engineer had formerly to rely upon the filtration through land of an effluent from chemical treatment to attain anything like a high standard of purity, a similar result was now obtainable in a limited area if skilfully laid out. He did not know what was the life of the chemical compound which was employed; but he had seen some of that compound which had been treated continually with water for three years, and there was none of the caking which those who had had experience of the subject knew that other spongy iron compounds had shown, and it appeared that, with the granular compounds used in this process, the filtering action was not interfered with at all after three years' use. Sometimes engineers were rather apt to make a dash at a system and to adopt it without having sufficient data to guide them. In this case the care and skill which had been shown by Mr. Lailey inspired confidence, and hence, to his mind, the system was free from some of those faults which over-sanguine inventors fell into very naturally. Perhaps he might be allowed to say that some years ago he noticed a singular intensification in the precipitating action of the crude sulphates of alumina by the addition of protosulphate of iron, or ordinary copperas. He was quite satisfied that by increasing the amount of persulphate of iron in sulphate of alumina, the efficiency was enormously increased. How it acted no chemist had explained. In that respect the case was like that of the compound now under consideration. He saw no reason why there might not be some special influence or effect produced by the spongy compound, which would cause a still greater intensifying action than that which he found out with reference to copperas. He should like to ask the author if he would give an analysis of the sewage itself, and then of the supernatant water which was drawn off from the tanks, as well as of the effluent water. He quite agreed with the author as to the desirability of eliminating lime from any part of the sewage treatment, either in the tank or in the sludge. He was sure that lime produced a mischievous effect upon the sludge and interfered with its manurial properties, and in the effluent itself, lime was a source of trouble, inasmuch as it produced decomposable compounds and confervoid growths.

Mr. R. Muirhead said that he had the pleasure of explaining the practical details of the pressing process to the

Members of the Society last autumn and therefore it was hardly necessary to go into that matter now. Mr. Strachan had alluded to the cost of pressing the sludge. He must say that the figures given by the author came to him as a surprise. He had not heard them before. The price was certainly high and did not compare favourably with the experience of the same work done elsewhere. He could only account for it by the fact that the amount of sludge which Mr. Lailey had to deal with at present was so comparatively small, and the charges for labour and incidental expenses were consequently high in proportion. At Maidstone, where the works were visited and seen in operation by the Association of Municipal Engineers a short time ago, they had presses which were regularly turning out 45 tons a week of pressed cakes, while working only up to about half their capacity. The total cost there had worked out at 1*s.* 4½*d.* per ton. He could not admit that any extra expense resulted from the direct-pressure system. At Maidstone a very small quantity of lime was added. About 140 to 160 lbs. was used for twelve presses. They found that on an average one lb. of lime was sufficient for one cwt. of cake. He thought that a little lime was desirable for pressing purposes, but it did not at all enter into the chemical treatment of the sewage proper at Maidstone. The lime was used simply to solidify the cake, and by means of it the cakes could be obtained in much less time than otherwise. Perhaps Mr. Lailey would inform them how long they took to press the cake at Acton. That might have a bearing upon the cost of production. At Maidstone the cakes were obtained in 30 or 40 minutes. They were satisfied with the direct process at Maidstone, and they had not the slightest misgiving with regard to it, or any feeling of regret at having adopted it.

Mr. W. Roebuck (Chairman of the Acton Local Board) said that they had a population of about 20,000 at Acton, and the works were capable of dealing with the sewage of 50,000. Mr. Strachan had remarked that they were only using one filter-bed for their three tanks, he would say in reply that the one was sufficient at present, and as the population increases the filter-beds can be extended. At present they dealt with the sewage from about 600 houses; the other houses were drained into the Metropolitan system. They were gradually connecting the remaining houses, and, of course, as new houses were built they all came into the new works. He was introduced to Mr. Candy a year and a half ago, and that gentleman showed him some experiments, and after testing those experiments for some nine months, he felt that he had got hold of the best system. He had also, in company with some members of the Local

Board—very practical men—and their engineer, visited many drainage works, and they were convinced from what they saw that the magnetic ferrous carbon process of purification was the best. The Board had entered into negotiations with a company using lime, but when it came to signing the contract, requiring them to give an effluent which would be satisfactory to the Thames Conservancy, that company backed out of their engagement without giving any reason to the Board. After this treatment he had sought some other process, and found the one now under discussion, possessing every requirement. The Board were perfectly well satisfied with it, and the system was working far better now than when they began. Everybody was becoming more accustomed to the management of its details. There was not the slightest doubt that sewage needed different treatment in different places. At Acton they had an enormous number of laundries, and he did not think that there was anything more difficult to deal with than soapsuds. Every one who had seen the sewage works expressed himself satisfied with the treatment. The inspectors and engineers from the Local Government Board had been down several times, and they had recommended parishes or townships which were in difficulty about their sewage to come and see the Acton works for themselves. He thought that that spoke well for a system which was comparatively a new one.

Mr. T. Farrall (of Sherborne, Dorset) said that the town from which he came was a small one compared with the district of Acton. The population was about 5000. They had no special sewage works such as Mr. Lailey had described, but the magnetic ferrous carbon was used in a very simple manner. The sewage from the town was originally discharged into the river, but when the Rivers Pollution Act came into force the sewer was diverted and taken into an arm or backwater, leading to the river. Here for some years the whole sewage, about 120,000 gallons per day, was discharged under treatment of carbolic acid and lime. Two wire strainers were fixed across the backwater to keep back the solids, &c., and two concrete weirs, with hatches, to keep up the level. But when the hatches were drawn the solids passed into the river, and in time the nuisance to neighbouring properties was such that in the spring of 1887 the magistrates made an order to abate the nuisance. One of the members of the Local Board who had visited the works at Acton thought that the system used there might be adopted in a simpler form, and he [Mr. Farrall] was instructed to ascertain about it. He accordingly communicated with Mr. Lailey and paid a visit to that place, where he met Mr. Candy and discussed with him the whole system of treatment. Since

then he had treated the Sherborne sewage with the ferrous carbon in a simple way, which had proved very efficient. The main outfall pipe was taken into a disinfecting chamber about 6 feet by 4 feet, with a series of slate bafflers to insure proper mixing of the materials. From this he built a channel the width of the pipe, and in this channel put a brass wire basket hung on centres. This basket was charged with the ferrous carbon, so that the sewage as it came down dissolved sufficient to precipitate and disinfect it. There were two precipitating tanks 20 feet by 12 feet, by 6 feet deep, one of which was emptied every week. The new works were put in operation last December, and had worked well from the commencement. The cost of tanks and all apparatus was under 200*l.*, and the cost per week, including materials and labour, was under 2*l.* There was no longer any nuisance, and the sludge was given to the neighbouring farmer for the cost of carting and removal. He (Mr. Farrall) believed that if they had proper means of pressing and grinding it, the cake would be a profitable commercial commodity.

Mr. F. Wentworth-Shields said that he had not gathered from the paper the amount of the purifying material used for mixing with the sewage, either per thousand gallons of sewage, or per head of the population, or what the cost of the material itself was. Those were two important items which it would be satisfactory to have, as the cost of the process could not be ascertained without them. He had seen the process in operation at Acton, and was extremely pleased, as he thought everybody must be, with the apparent result. As had been said, the first effluent was rather turbid, but after it had passed through the filtration chamber, it was as clear as clear could be. He wished to ask Mr. Lailey what had become of the flocculent matter which had been floating in the first effluent. He presumed that it must be caught upon the surface of the filter-bed, which was formed, so far as he understood, of a rather coarser sand than was used for waterworks filtering, and this might account for its passing so much as 2500 gallons per square yard per day. He supposed that that sand must require renewing or cleansing in some way, and would ask what process was required to cleanse the surface of the filter-bed from that turbid matter. In other respects he understood that the filter was everlasting, and that the deodorising material in the filter-bed below the surface sand never required renewal or further attention.

Mr. T. Roberts (of Ludlow) said that what they had at Ludlow was merely settling tanks, and that as soon as they had got clear of their debt with the Local Government Board,

he had no doubt that fresh tanks, or some other improved scheme would be adopted.

Mr. W. Lee Beardmore said that he had gathered that at Acton it was the practice for the district surveyor to give certificates as to the sanitary condition of the drains in private houses. He must say that that seemed an important task for a district surveyor in a large district like Acton to perform. To examine the drainage arrangements of a house required the devotion of a large amount of time, and as those of large districts such as Acton could scarcely be properly examined by the surveyor, with all his many other arduous duties, if the surveyor himself could not make the examination, the duty would no doubt devolve upon the sanitary inspectors. House-drainage did not merely consist in disconnecting the house-drains from the public sewer by a siphon-trap. There was a great deal more to be done, and every joint of a drain ought to be personally inspected by a qualified engineer when it passed from the hands of the builder. His experience showed him that sanitary inspectors under district surveyors were often recruited from very peculiar sources. At Ealing, special regulations with regard to house drainage had to be complied with, but yet it could not be said of many houses that they were in a sanitary condition. It might be within the recollection of many persons present that recently there had appeared in one of the daily newspapers a leading article relating to a case in which the assurance of a district surveyor had been given as to a house being in a sanitary condition. The house was found to be otherwise, and the tenants took proceedings against the landlord, and the landlord was mulcted in a large amount of costs. There was another point with regard to such certificates; supposing a certificate were given, alterations might be made afterwards. Should that certificate then hold good in such a case? As to the joint to which Professor Robinson had alluded, he quite agreed with Professor Robinson's remarks. That joint might be very admirable for temporary purposes, but in his opinion, it was not well adapted for permanent work, even if it was laid upon a firm bed of concrete. Not long ago he was told by a large firm of builders that it was their practice to run joints of stoneware pipes with asphalte. That idea seemed to be an excellent one, and it would cost very little to make an experiment with such joints to ascertain their efficiency.

Mr. Edwin T. Hall, speaking as an architect, said that the system of house drainage mentioned by the author of the paper seemed to him to be defective in one or two important features. One was the lack of ventilation of the drain at the highest point in the horizontal pipe. Another point was that

there were no means whatever of cleansing the drain. In his own practice he adopted the following very simple system. At the extreme end he brought a branch up to the surface and inserted in the top pipe one of Messrs. Doulton's stoneware plugs set in white-lead. The simple removal of this enabled the drain to be swept from end to end. He thought that one of the joints described might be a most valuable one where it was adopted in vertical systems; but he agreed with Professor Robinson that for a drain to have flexible joints was a most serious evil, as it might lead to a leakage under the houses in case of the sinking of the ground. If the trench for the drain were dug too deep it would in common practice be filled up with loose material, and in time there would be a local settlement, whereas an inflexible pipe in all ordinary cases would bridge over the sinkage. Another evil of the joint would be that the cavities between the ends of the pipes would become charged with deposit, which would form a ledge against which solid matters in the sewage would be caught. It would be very difficult, especially where the pipes were laid, as they were at Acton and other places, embedded in cement concrete.

Mr. J. W. Wilson, Jun., said that a great deal of evil was brought about by the incompetence of sanitary inspectors. He had been called in a few months ago by a client of his for advice in a case in which official notice had been served by the sanitary inspector, stating that the house closets had not been disconnected from a cesspool which stood underneath the back kitchen floor, and which had been merely covered with loose stone flags. The notice stated that, in default of the matter being at once remedied, steps would be taken of a very serious nature. He (Mr. Wilson) was obliged to meet the sanitary inspector on the spot, and point out to him that the pipes running underneath the kitchen were simply rain-water pipes from the roof of the house, running into a soft-water tank. He pointed out to the inspector that there was a pump communicating with the tank, which obviously could not be intended to pump up liquid sewage into the back kitchen sink, and the inspector was obliged to admit that he had been misinformed, and had issued the notice in question without warrant. He had, it further appeared, simply no knowledge of the nature of the district. He did not even know that there was a main drain running down the road, and he thought that the whole system of drainage was into cesspools. There were, however, sanitary inspectors and sanitary inspectors. Many of these officers were very clever men in their work, and he was glad to notice a tendency to improvement in an important service.

Mr. R. J. G. Reed, a member of the Local Board of Acton,

and of the Drainage Committee, said the Acton Board had the advantage of having as their chairman an engineer who was a thoroughly practical man, and he it was who had brought the present scheme before their notice. The works at Acton were situated very close to the fashionable district of Bedford Park, and if there were the slightest nuisance arising from the works, immediate action would be taken against the Board, but up to the present they had not found the slightest nuisance. The works had turned out really more successful than he had anticipated; but they had not had a sufficient time to judge of them thoroughly. Many difficulties had presented themselves in connection with the carrying out of the works. There was a great difficulty in getting rid of the effluent as the outlet to the river which the parish once possessed by way of the Stamford Brook had been cut off when the Metropolitan Board of Works took the brook into their sewer, and consequently the Acton Board had to pay for the right of easement through Chiswick to the Thames. Also, because of the injunction obtained by the Metropolitan Board, the parish had been put to great unnecessary expense in running new sewers up to isolated houses in the midst of those draining into the Metropolitan system. As to the general carrying out of the work, he had watched it very critically, and he believed that it had been thoroughly well done. He had seen conclusively that there was a distinctly good purifying power in the material with which the sewage was treated, although he could not gather what the precise action of the material was, whether the material acted as an oxidiser in itself, or whether it acted merely as a carrier, taking oxygen from something else and giving it to the putrefiable substances. The result of one experiment might, perhaps, be interesting. People often went to sewage works to see the effluent; and, though it was said to be as pure as drinking water, very few people liked to try it. He had, however, been one day tempted by its clear and sparkling appearance to taste it, and he could say that there was nothing particularly noticeable in the taste at the time, it was just like ordinary drinking water; but after a while there was a very strong flavour of something resembling a mixture of ink and sea-water, which he could not get rid of for an hour. He should like Dr. Angell to tell him what the constituents of that taste were. He was perfectly convinced, from the samples of the effluent which they had had standing about, that there was very little organic matter in it; if there was no more in it than had been described in the analyses there was not much to fear. He agreed with the remarks of some of the speakers, that there ought to be definite analyses and quantities and tests of the

various kinds of sewage and of the results of the processes, and now that the works were practically finished, he hoped that Mr. Lailey would have time to go into experiments of this kind. When that was done they would get some valuable information.

Mr. JAMES DOULTON, in answer to some remarks by former speakers, said that the self acting joint, while it was uninjured by any settlement of the ground, was certainly not designed to encourage bad workmanship in the laying. It was in the first place intended as a reliable joint, which could be very readily put together, no matter how unskilled the labour employed, and its flexibility was only an additional advantage which prevented damage to the drain arising from any accidental disturbance of the pipes after being laid. It was this certainty in laying, combined with its flexibility, which made the self-adjusting joint so much superior to the Stanford's.

Mr. F. CANDY, as Managing Director of the International Water and Sewage Purification Company, wished to tender his warmest thanks to the Acton Local Board, and also particularly to Mr. Lailey, for giving the system a trial. Before fully carrying it out, the system had to undergo a thorough investigation on the part of committees, which apparently were satisfactory, for the Chairman of the Board and the engineer desired him to make experiments upon very large quantities of the Acton sewage. The result was that the Local Board entered into a five years' contract with the International Company. He desired to have the process thoroughly investigated. Eminent sanitary engineers and Local Board officers had looked favourably upon the process, as if they considered that an opportunity had come at last for getting rid of the necessity of acquiring large areas of land for the treatment of sewage. As an instance, he might mention that it was estimated that by the magnetic process, the London sewage could be dealt with effectually on 50 acres, instead of requiring 50,000 acres. The advantage was evident in districts where land was not suitable in quality, or could not be obtained in sufficient quantity for sewage farming, and even then sewage farming almost invariably led to a perpetual nuisance. At Wimbledon there was an excellently managed sewage farm of 70 acres, worth at the present time nearly 1000*l.* an acre as building land. Now the whole of the Wimbledon sewage effluent could be dealt with by the magnetic process in about 600 square yards, at a great saving of cost. The authorities there, although the greatest care was exercised, were yet obliged last year to use permanganate of soda, a most costly chemical, which, although a good antiseptic, is practically useless for purifying sewage. The engineer had lately been using the magnetic ferrous carbon in place of permanganate

and sulphate of alumina, with good results, both of effectiveness and economy.

Mr. Lailey, in reply, thanked the members of the Society for the attention which they had given to the paper. He had endeavoured in his paper to lay before the Society as truthful a statement as he could of the actual experience gained from the works at Acton. As he stated in the paper, the population draining into the metropolitan sewers at Acton was 17,000. The remainder drained into the new outfall. The number of houses thus draining was 600. The quantity of sludge produced from the drainage of those houses was 4½ tons of pressed cake a week. Mr. Strachan had asked why the price of the pressing was so high. The explanation was that for the six months during which pressing had been going on at Acton, it had required 2½ hours to press one ton of sludge, but within the last fortnight a new powder had been obtained to be added to the wet sludge, which would reduce the time of pressing to an hour and ten minutes without the use of lime. The paper was written before this change took place, and he had not altered it, intending to give the new figures in the course of the discussion. Mr. Strachan had remarked upon the depth of the sludge well. That well was not in the pressing shed. It was the grinding room over the sludge well that Mr. Strachan had spoken of, and that was 12 feet high. The lift of the sludge was 12 feet to the floor. As to the filtration area, that was 190 square yards. His statement that 2510 gallons per square yard could be filtered in 24 hours was founded on weekly experiments, taking the figures day after day. Mr. Doulton had replied to Professor Robinson's remarks on his self-adjusting pipe joint. Since he had first used the Doulton joint, Archer's patent air and watertight joint had been introduced to him. He hoped to use that joint in the next drains which he constructed. It was very similar to Hassal's, which was described in the paper. A question had been asked as to the cost of the precipitating material for the population now draining into the works. The material cost 4*s.* a day upon 150,000 gallons. Mr. Beardmore had made some remarks upon the system of house drainage, and somewhat of a raid had been made upon building inspectors. The Acton Local Board had given much time and attention to this matter, and employed straightforward and hardworking men who thoroughly understood their business. Three clerks of the works had been continually employed. One of these gentlemen happened to be a member of the Society, and, judging from the discussion which had taken place, he thought it spoke well for a man that he belonged to such a body. The other two were trained men, and equally practical.

VACATION VISITS.

In the summer of 1888 three visits were made to works, entirely differing in character, but each forming an important example of the particular department of engineering.

The works of the Tower Bridge were visited on the 26th June, the members being received by Mr. Cruttwell and Mr. Jackson.

The idea of making this structure a bascule bridge originated with the late City Architect, Sir Horace Jones, but in 1884, when the Corporation decided upon its construction, Mr. John Wolfe Barry, M.I.C.E., became associated with Sir H. Jones, and their joint design was submitted to a Committee of the House of Commons in that year; the sanction of Parliament was, however, not obtained until the autumn of 1885.

The works were commenced in 1886, and since the death of Sir H. Jones in 1887, the whole undertaking has been under the charge of Mr. Barry.

The Tower Bridge will be built in three spans, of which the two side spans will be fixed. The central span will be of peculiar construction, being in two levels, the lower one of which will be capable of being opened for the passage of vessels, the upper one being a fixed bridge for the passage of foot passengers when the lower part of this span is open for river traffic. The headway of the side spans will vary from 20 feet to 27 feet above Trinity high water, and the headway of the central span, when open for the passage of vessels, will be 135 feet above the same level, which is more than ample for the masts of ships frequenting the Thames. When the lower portion of the central span is closed, the headway will be 29 feet 6 inches above Trinity high water. The width of the side spans will be 270 feet, and of the central span 200 feet. The width transversely of the bridge and its approaches will be 60 feet, diminishing to 50 feet at the central span. The gradients of the approaches to the bridge will be remarkably easy, and superior to those of London Bridge, the worst being 1 in 40. The opening of the Tower Bridge will be effected on what is known as the bascule principle, viz. the movable portion of the bridge, instead of revolving, like most opening bridges, on a vertical axis, will hinge on a horizontal axis, so that the leaves of the bridge will open upwards, and will be raised high in the air when the bridge is open for the passage of vessels.

This mode of operation avoids the great interference which would be caused in the case of an opening bridge of the usual type revolving in a place so crowded with traffic as the Pool.

The two piers of the Tower Bridge are exceptional in their dimensions and construction. They are 70 feet wide, and are hollow, so as to receive the counterbalanced ends of the opening leaves of the central span. The foundations of the piers are constructed by sinking wrought-iron caissons into the bed of the river. These caissons are filled with Portland cement concrete up to a certain level, and from that point upwards the piers are constructed of Cornish granite and brickwork in Portland cement. On each of the piers a lofty tower will be erected, the tops of which will receive the upper ends of the suspension chains of the side spans, and will also support the high-level foot bridge across the central opening. In the towers there will be hydraulic lifts for giving foot passengers access to the high-level footway, and stairs will also be provided. The mode of actuating the two leaves of the bridge will be by rotary hydraulic engines, acting through gearing on four quadrant racks applied to the rear ends of the bridge. The contract for the hydraulic machinery for actuating the lifting portions of the bridge will be carried out by Sir William Armstrong, Mitchell and Co., of Elswick, who have, in conjunction with Mr. Barry, worked out all the details of the machinery. The steam engines for actuating the hydraulic machinery will be placed on the southern side of the river beneath and adjoining the southern approach to the bridge. They will consist of two engines of 360 horse-power each, taking steam from four boilers. Four of the accumulators will be placed upon the piers and two upon the south side of the river. The weight of steel and iron in the chains and girders will be about 7000 tons. Each of the leaves of the bridge will weigh about 350 tons. The superficial area of each leaf will be about 5000 square feet.

The hydraulic machinery has been made of sufficient strength to control the bridge in a wind exercising 56 lbs. pressure per square foot, and, moreover, the whole of the machinery is in duplicate.

On the occasion of the visit in question, the members were conveyed by steamer to each of the piers in succession, and afterwards inspected the northern approaches The details of the works are most interesting. The piers are being built within water-tight caissons, twelve in number for each pier. The caissons are sunk round the circumference so as to enclose the central portion of the pier. On each side, north and south, are four caissons 28 feet square, and at each end are two 35-foot

caissons of a triangular shape to form the cutwater of the piers. The caissons, when sunk, are filled with concrete to near the level of the bed of the river, at which height the granite face work begins. Junctions are then formed between each pair of adjoining caissons by driving piles between them; the adjoining sides of the caissons are removed, and the masonry and brick-work backing are built continuously all round the pier. The wall thus built acts as a cofferdam for excavating the central portion of the pier. The foundations beneath the river bed are 90 feet by 195 feet from outside to outside of the caissons, and the foundations are further extended all round the pier by undercutting 5 feet beyond the edges of the caissons. The caissons extend 20 feet beneath the bed of the river, or 53 feet beneath Trinity high water, and the undercutting is carried down 7 feet beneath this level. The piers above the bed of the river are 70 feet by 185 feet, with the ends curved to form the cutwaters. At the time of the Society's visit, all the caissons of the north pier were sunk, and the wall surrounding the central portion of the pier nearly completed up to 4 feet above Trinity high water; but only the six caissons on the south side of the south pier were at that date sunk, because by the Tower Bridge Act a clear waterway of 160 feet must be maintained, and, therefore, it would be necessary for the staging to be removed from the north pier before a similar one could be fixed on the north side of the south pier. The north abutment of the bridge had then been built to a height of 14 feet above high water, and the south abutment had been commenced. The northern approach to the bridge was built up to the road level, except a portion next the abutment, which was left uncompleted until the anchorage for the suspension chains of the shore span could be fixed. The southern approach had not yet been commenced, but was intended to be proceeded with at an early date.

The second visit was to the New Precipitation Works at Barking Sewage Outfall, on the 24th July, 1888, the members being received by Mr. G. Marshall, on behalf of Sir J. W. Bazalgette, C.B., Engineer to the Metropolitan Board of Works, and entertained at luncheon by the contractors, Messrs. John Mowlem & Co. The following remarks must be considered as applying to the condition of the works at that time.

The whole of the sewage of the metropolis north of the Thames is conveyed to Barking Creek by three culverts, each 9 feet high by 9 feet wide, and is, in the first instance, delivered into a covered reservoir divided into four compartments, and altogether extending over an area of 9 acres. The sewage is

stored in this reservoir during eight hours of each tide, and discharged into the river at high water at the top of the ebb. This reservoir is situate on the east side of the sewer and immediately adjacent to the river bank.

The new works consist of covered precipitation tanks adjacent to this reservoir on its north side and occupying the ground between the Outfall Sewer and Barking Creek, an area of between 10 and 11 acres.

There will be 13 of such tanks, each 31 feet 6 inches wide, and averaging about 1000 feet long. Communications will be made between the Outfall Sewer and each of these tanks, by two penstocks in each instance, so that communication may be opened or shut off at pleasure.

The sewage will be admitted into each of the tanks in succession, and the precipitation of the solids in the sewage expedited by the admixture of 3·7 grains of lime and 1 grain of protosulphate of iron per gallon, the effluent being run off over a weir which will fall as the water in the tank lowers, so that the top film of the effluent only will be taken off, and the tank emptied gradually, thereby preventing any disturbance of the solids by the operation.

The effluent after flowing over the wiers (of which there will be ten in each tank) will pass into culverts carried transversely under the tanks and extended,—some into the compartments of the existing reservoir—and some into a chamber under the Outfall Sewer, through which at present the sewage is discharged into the river from the existing reservoirs. When the level of the tide will admit, the effluent will be discharged through this chamber direct into the river, but when the water in the river is too high to admit of this, the effluent will be conveyed by the other culverts into the several compartments of the present reservoir, and stored there until the level of the water in the river will admit of its discharge.

When each compartment is emptied of the effluent, the sludge, in a semi-liquid state, will be discharged through culverts passing under the Outfall Sewers into a collecting culvert, and thence conveyed by pipes into a receiving well or sump, and pumped into a series of twelve tanks placed side by side, and situate between the Outfall Sewer and the river. These tanks will each be 20 feet wide and 140 feet long, will cover an area of over an acre and a half, and, like the precipitation tanks, will be covered so as to prevent nuisance.

The sludge will be allowed to remain quiescent in them so as to allow of a further precipitation, and the effluent water will be discharged over wiers into a culvert which will convey it into a store under the tanks, from whence it will be lifted and

discharged through pipes to the liming station, there to be mixed with lime which is used for precipitation.

The settled sludge remaining after this further precipitation, will be discharged through culverts into a sludge store situate under the tanks, and lifted thence and conveyed by pipes along a jetty to a landing stage to be erected in the river, and there discharged into ships which will convey the sludge to sea. In the event of the ships being detained by stress of weather there is a further store for sludge at a lower level extending under the whole of the area occupied by the upper stores.

On the north side of these sludge settling tanks will be erected engine and boiler houses and workshops in connection, to contain engines and machinery for lifting the sludge into the settling tanks, and the settled sludge into the ships, as well as for pumping the sludge effluent to the liming station.

The lime for assisting the precipitation of the solids of the sewage is introduced into the Outfall Sewers at a point about 700 yards, and the proto-sulphate of iron about 530 yards, above the precipitation channels.

The liming station will comprise a lime store, floors for slaking the lime, and six tanks for mixing the slaked lime with the effluent water from the sludge settling tanks or with sewage taken direct from the Outfall Sewers; an elevated lime-water tank or reservoir built above the lime store, and into which the lime-water will be lifted by pumps, for which machinery and the requisite engine and boiler houses will be erected adjacent to the lime stores. From this elevated tank the lime-water will be conveyed to and injected into the sewage passing along the Outfall Sewers, through cast-iron injectors placed in the sewers.

There will be means of turning the lime-water into any one of the three lines of sewers, and of regulating the supply by means of sluice-valves fitted to the pipes leading to the injectors. The injectors consist of cast-iron chambers 4 feet 6 inches in length, 6 inches wide, and 6 feet in height, fitted with a number of nozzles, through which the lime-water will be injected and mixed with the volume of the sewage as it flows past.

The iron-water station comprises timber sheds for storing the proto-sulphate of iron, a mixing shed in which the iron will be crushed and mixed with water, an engine shed to contain engines and machinery for crushing the iron and mixing it with water, as well as for raising water for boilers and into mixing tanks. The iron-water will be conveyed by stoneware pipes, carrried underground and along the top of the Outfall Sewer into a service tank, from which it will be carried

by pipes into each of the three Outfall Sewers, and injected into the sewage through perforations in a pipe fixed vertically in each of the sewers. As with the lime-water, there will be appliances for regulating the supply of iron-water to each of the sewers to meet the varying requirements of the discharge.

There will be a large settling pond, covering an area of 1¼ acre, situate near the river, divided into six compartments, each 60 feet by 60 feet, and about 7 feet deep, into which water will be received from the river and allowed to settle, the clear water being afterwards filtered and used for the supply of the several boilers, for slaking the lime, and for mixing with the proto-sulphate of iron.

The jetty, which will extend 576 feet into the river from the present river bank, will be 15 feet wide, and will be a timber structure supported upon piles.

At the river end of the jetty will be a timber landing stage 300 feet in length and 20 feet wide.

The iron pipes for conveying the sludge to the ships will be carried under the platform, and will be furnished at the end with a delivery pipe, socketed to admit of a vertical movement, so as to discharge the sludge into the ship at varying levels of the tide.

A tramway will be laid along the full length of the jetty, connecting it with the whole of the works.

The contract for the works includes the erection of twelve cottages and a residence for the superintendent, and the diversion of the Old Galleons sluice and ditch, which is one of the main sewers under the jurisdiction of the Essex Commissioners of Sewers.

There will be a large quantity of surplus earth from the excavations, which will be used in forming the banks for the tramways, and in raising the general level of the ground, which is now 6 or 7 feet below the level of Trinity high water.

The works extend over an area of about 50 acres, the quantity of sewage to be dealt with will amount to about 90,000,000 gallons per day, and the quantity of lime to be used in precipitation to 23 tons per day.

Two contracts have been entered into for the execution of the works, one with Messrs. Mowlem and Co., for the general work, for 406,000*l.*, and the other with the Glenfield Company of Kilmarnock, for engines and machinery, for 42,567*l.*

The third visit was to the London and South-Western Railway Locomotive Carriage and Wagon Works at Nine Elms, on Tuesday, 25th September, when the members of the Society and their friends were received and entertained at luncheon by

Mr. W. F. Pettigrew, on behalf of Mr. William Adams, who was unavoidably absent owing to illness.

These famous works, which were originally designed by the late Mr. Joseph Beattie, have been, owing to the increase of traffic and stock, considerably altered and enlarged by Mr. William Adams, the present Superintendent.

The works, which cover 45 acres of ground, are situated at Nine Elms, and afford employment to between 2000 and 2500 men.

The Locomotive Department comprises a number of shops, foundries, &c., among the most important of which are the following, viz. the "short" machine shop, which is a brick building 164 feet long by 57 feet wide. It is well fitted with the most modern classes of machine tools, milling machines being conspicuous by their large numbers. A very massive profile milling machine is also used for machining such articles as "expansion-links," "jaw and T-ends of eccentric rods and connecting rods." There is also a very massive frame plate combined slotting and drilling machine, capable of slotting 12 steel plates, 1 inch thick, at one time. The drilling is done by three of Craven Brothers' radial drilling machines, having a radius of 10 feet 6 inches, which overhang the table of the slotting machine. This arrangement considerably diminishes the amount of time and labour, as plates can be slotted and drilled at one setting. We also find here numerous slotting, planing, and boring machines, a duplex coupling-rod planing machine, and a circular saw for cutting cold iron, which latter is found to save much time and labour in cutting out such work as the jaw-ends of rods, &c. Leaving the "short" machine shop, we enter the cylinder shop, which is provided with a very useful overhead travelling crane, made at Nine Elms. Here were noticeable two very fine vertical milling and drilling machines, used for machining the valve faces of cylinders; also a radial drilling and tapping machine, in connection with which is used "Pearn's" patent tapping apparatus, by the use of which cylinders can be drilled, tapped, and studded with one setting. The cylinder boring machine is adapted for boring two cylinders at one time. This shop is 57 feet long by 29 feet wide. Entering the fitting shop (118 feet long by 58 feet wide), arranged upon the most approved plan, we notice several "vortex blast pipes," the invention of Mr. W. Adams, the adoption of which has led to a great saving of fuel, as proved by the gradual decrease of coal consumption during the last three years on the South-Western Railway. We may here mention that the average consumption of fuel in 1885 was 30 lbs. per engine mile, which has now been reduced

to $26\frac{1}{2}$ lbs. per mile, effecting a total saving, since June 1885, of nearly 34,000*l.* There are at the present time nearly 300 engines, on the South-Western Railway alone, fitted with this pipe, and it is giving very great satisfaction. Coupling-rod bushes are now made solid, without adjustment, and are forced into the rods by means of a small hydraulic press recently made at Nine Elms. Passing into the brass shop (59 feet long by 45 feet wide), we find it provided with the most modern appliances for brass finishing, amongst which may be mentioned four "Cooper's patent lathes." In this shop is made the white metal piston and valve-rod packing, which is a standard now with all new engines of the South-Western Railway, and is giving the greatest satisfaction. There is a pressure-gauge testing machine, and also one of Edward's patent emery-band grinding machines, which has proved very valuable for finishing all kinds of brass fittings of irregular shape. We then enter the millwrights' shop, a building 85 feet long by 58 feet wide, fitted with modern machinery, including two universal milling machines, cutter grinding, slotting, planing, and shaping machines. In this shop are made the twist drills, taps, reamers, and small machines which are used throughout the shops at Nine Elms. The "long" machine shop (300 feet long by 57 feet wide, the standard width of the shops at Nine Elms) was next visited. The machinery is actuated by a vertical engine making 100 revolutions per minute. All machines of one class are placed together. Screwing machines are the first to attract our attention, the most modern of which are Barrow's patent, capable of screwing some 800 copper stays in the course of a day. Further on are larger machines of the same class for dealing with square-threaded screws of carriage couplings, &c. In the same shop are numerous small lathes, shaping machines of all sizes, a very heavy brake lathe, and a very massive crank axle lathe by Craven Brothers, of Manchester, having four rests, all of which may be used at one time. A piston-rod grinding machine is here in use. The rods are first roughed down in the lathe and finished off here. Mr. Adams was the first to use this form of labour-saving tool, which has given very satisfactory results. Nearly all the drilling machines at Nine Elms are fitted with balanced spindles, and this is found to save the breaking of many drills. Entering the wheel shop, which is 195 feet long by 57 feet wide, we find five 7-foot, two 6-foot, and one 4-foot lathe. These are served by two 4-ton "walking" cranes, to which motion is communicated by an endless cotton rope. In this shop are also the usual quartering, axle grooving, and wheel studding machines. There is also a tyre furnace and shrinking

well, which are served by a separate fixed crane driven by an endless rope.

The erecting shops consist of two bays, each 500 feet long by 57 feet wide, having accommodation for 70 engines. There are three roads in each bay. Each erecting shop is provided with two 25-ton overhead travelling cranes, capable of lifting an engine bodily from one road to another. There is in all 2000 feet of line shafting, which runs in cast-iron self-acting pedestals, and is provided with Mather and Platt's friction clutch, so as to enable any one length to be disconnected at will. Hydraulic piping, supplied with water at a pressure of 1500 lb. per square inch, is laid throughout the entire length of these two shops, so that small hydraulic tools can be worked from this source of power. In these shops will be noticed several of Mr. Adams' bogies, steel being freely used in their construction. From thence we pass across the steam traverser, which has recently been lengthened, and is capable of carrying an engine 30 feet wheel-base into the tender shop. This building is 90 feet long by 51 feet wide, and is fitted with a Tweddell's small hydraulic riveter, and a 25-ton overhead travelling crane driven by an endless rope. A visit was next paid to the boiler shop, which is 178 feet long by 116 feet wide, and fitted up with the most approved appliances as used in the manufacture of locomotive boilers. This shop is divided into two bays, the first of which contains the machine tools, and is fitted with a 15-ton overhead travelling crane by Craven Brothers, of Manchester. There has also been recently fixed a pair of horizontal plate-bending rolls by Craig and Donald, which are capable of bending steel plates 8 feet wide by $\frac{3}{4}$ inch thick. All the rolls are of solid steel, and the top roll is capable of adjustment by power from the main driving pulleys. There is also in this part of the shop a plate-grinding machine which has been recently made at Nine Elms, and is found to be thoroughly efficient. A very large number of boilers are in progress of manufacture. Steel, with the exception of the firebox and tubes, is wholly used in their manufacture. Manganese steel stays are now replacing copper for the firebox. In the adjoining bay is fixed one of Tweddell's stationary hydraulic riveters, having 11 feet 6 inches gap. In connection with this is a 7-ton hydraulic crane. Along the adjoining wall are fixed six smiths' fires. Close by are two large plate-heating furnaces, and one of Tweddell's flanging presses, which are served by one crane. At the mouth of one of the furnaces is a very massive levelling table, upon which the steel frames for engines are levelled after being punched roughly to shape. In the same part of the shop is fixed a large punching and shearing machine, by F. Berry

and Co., which is capable of punching $1\frac{1}{2}$-inch holes in $1\frac{1}{2}$-inch plates, 3 feet from the edge. Continuing our journey we arrive at the hydraulic engine house, in which is fixed two pairs of engines by the Hydraulic Engineering Company, of Chester. These supply water at a pressure of 1500 lbs. per square inch to an adjoining accumulator, from which all the hydraulic tools in these shops, including three turntables, are worked. We then make our way into the smiths' shops, which is 194 feet long by 57 feet wide, and contains 26 forges, inclusive of bolt-makers' fires, five steam hammers, and various other tools and appliances. Blast is supplied to the forges by a Baker's blower. Recrossing the traverser road we enter the forge and spring makers' shop (176 feet long by 51 feet wide). Along either side of the building are arranged the forge furnaces, over which are placed locomotive boilers, and fed by the waste gases from the furnaces. These boilers supply steam for working the hammers, &c. Between the furnaces are arranged the steam hammers, which consist of two of Rigby's 35 cwt., one 7 cwt., and one 20 cwt. These hammers are served by hand-power cranes which were made at Nine Elms. Leaving this shop we come to the three cupolas with drop bottoms, the largest of which is capable of melting 8 tons of iron per hour. In connection with these there is a steam hoist for taking the materials up to the charging level. We now enter the iron foundry, which is served by two 5-ton steam cranes by Appleby Bros., from whence we again cross the traverser road and enter the carriage building shop (194 feet long by 60 feet wide), in which the bodies and under-frames of coaches are built. The shop is heated by exhaust steam. We now pass into the first bay of the saw mill, where is fixed a very fine log frame saw; also a 4-foot band saw. The far end of this building is utilised as a pattern-makers' shop, in which is fixed a dimension sawing machine, a band saw, and a hand-feed planing machine. Entering the second bay of the saw mill (194 feet long by 78 feet wide), we find a panel planing machine by Ransome and Co., and a power-feed sand-papering machine by Fay and Co., which is used for the mahogany panels of carriages. The cylinder over which the sand-paper is placed has a flexible covering. Adjoining this is a four-sided planing and moulding machine; also a panel-scraping machine, the action of which resembles that of an ordinary hand plane. At the end of the shop is a double band sawing machine by George Richards and Co., of Manchester, and there is a variety of other wood-working machinery of that firm's manufacture. We must not forget to mention an American rack saw bench by the Lane Manufacturing Company, and which is capable of

carrying a 66-inch saw, which runs at 500 revolutions per minute. It has levers set and a very fast return feed. All the sawdust, &c., is automatically conveyed by a fan to a collecting tower, from whence it is utilised to raise steam in one of the stationary boilers. The whole of the shafting for driving the various machines is fixed below the floor, which arrangement keeps all the driving bands out of the way, and does not necessitate the use of countershafts.

Leaving the saw mill we proceed to the carriage machine shop (194 feet long and 57 feet wide), where the line shafting is carried on cast-iron columns, and driven by a vertical engine, coupled direct. The far end of this shop is utilised as a grindery, in which are fixed five 7-foot grindstones. Twist, drill, and slide-bar grinding machines are also to be found here. The Baker's patent blowers for supplying the air to the various smiths' shop fires are fixed in this shop. Again crossing the traverser road we enter the carriage smithy, which is 176 feet long by 51 feet wide. Here are eight steam hammers, the majority of which were made at Nine Elms, used for stamping small forgings when required in any quantity; also three saws for cutting hot iron. There are in all 23 smiths' fires, inclusive of bolt-making furnaces, arranged on either side of the building. Resuming our journey we make our way into the new running shed (235 feet wide by 180 feet long), capable of holding 60 engines. It is served by a 50-foot hydraulic turntable. Making our way from here we enter the machine shop for ordinary running repairs. This shed is served by two 42-foot hydraulic turntables. Leaving here we proceed up the steam traverser road and pass through the carriage repair shops, which consist of two bays, each 254 feet long by 57 feet wide, and not calling for any special remarks. The carriage paint shop is a well-lighted building 210 feet long by 151 feet wide. It affords accommodation for painting between 60 and 70 coaches, and is heated on the "Perkin's" principle. Adjoining this shop are the wagon repair shops, consisting of two bays, each 208 feet long by 57 feet wide. Above these are wagon building and carpenters' and finishers' shops, a corner of which is utilised as a paint store, fitted with the usual paint mills, &c. On the same floor is the tinsmiths' shop, trimmers' shop, and general offices. Underneath these are the carriage repair and wheel shops. They consist of three bays, one 18 feet, and two 57 feet wide by 130 feet long. In this shop are 10 carriage and wagon wheel lathes, and hydraulic press and pumps for putting on and taking off wheels. In the smaller bay adjoining is fixed a multiple spindle drilling machine for Mansell's wood wheels, which tightly locks the wood segments together and

drills all the holes, including the centre large one, at one operation. Beyond these shops are two sheds, one for lifting carriages and the other for lifting wagons. At the east end of the works, i.e. towards Vauxhall Station, is situated a large shop 225 feet long by 170 feet wide, in which is made the road vans and out-station furniture. Four of the arches under the main line are fitted up as dining halls for the workmen; the remainder being used as shops and stores.

The South-Western Railway has now in operation about 850 miles of line, and is served by 550 locomotives, 3000 carriages, and 8000 wagons.

October 1*st*, 1888.

ARTHUR T. WALMISLEY, PRESIDENT, IN THE CHAIR.

LIGHT RAILWAYS.

BY WILLIAM LAWFORD, M. INST. C.E.

TOWARDS the close of last year the author was favoured with a communication from the President, proposing that he should undertake, in the course of this year, to prepare and read a paper on Light Railways to the members of this Society, which request, after some consideration, was acceded to by the author, although, while so doing, he was aware that the subject was trite and well worn, amongst civil engineers at least, having been well gone into and ably discussed on various occasions some fifteen or twenty years ago. He therefore does not suppose that any specially new light can be thrown upon it now, or that it can be invested with a greater degree of interest than it possessed at that time; nevertheless it may be hoped that the subject may still be worthy the attention of the Meeting for a brief period this evening, and that its reconsideration may be profitable in endeavouring to show what has been done during the interval that has elapsed since the year 1868, when the author's attention was first drawn to the subject.

With the exception of some few short lines, which may be counted on the fingers, light railways do not appear to have found favour with the British public, i. e. they have not proved to be a commercial success, and the reason of this, in the author's opinion, is not far to seek. The cost of land and the construction of works have been in excess of that anticipated, and the traffic has been the reverse: in fact, the lines have been starved, this no doubt being in many cases due to the bad traffic arrangements made with the main lines of railway (to which these light branches ought to be feeders). For instance, probably two, or at most three, trains per day are run each way, at inconvenient hours, and arrive at the junction with the main line twenty minutes or half an hour late, thereby destroying the connection and causing a detention of perhaps a couple of hours or even more, to the unfortunate passengers; such an arrangement, it need hardly be said, should not be

allowed to exist; again, most of us know that if machinery is to be made to pay, the more it is kept going the better, and if that machinery happens to be a light railway, every practicable facility should be given to induce the public to travel over, and to send their goods by it. Rigid punctuality should be insisted on by the traffic managers, especially as regards the passenger trains. It is not here to be understood that a more frequent daily train service is advocated than is needed by the requirements of the locality, as half-filled trains will scarcely cover even working expenses, but it may with justice be said, that in this country light railways have scarcely yet had a fair trial. With a lighter permanent way, lighter rolling stock, and a somewhat slower speed than usual on heavy lines, there is really no reason why light lines should not become remunerative, especially in farming and agricultural districts, where the population is too small and too much scattered to warrant the outlay required for an ordinary, or heavy line of railway. And it is self-evident, that if advantages are to be reaped from light railways, our Legislature ought to give greater facilities for their construction. If it can be shown that they can be made remunerative, Parliament ought to be petitioned for a Bill which should be not only in name, but in reality a "Railways Construction Facilities Act."

While this paper was in course of preparation it occurred to the author that it might be beneficial to ascertain how far the above-named Act had been made use of, and whether such lines, if constructed, would come under the category of light railways. For this purpose the Assistant Secretary of the Railway Department of the Board of Trade was applied to, who kindly in return sent a letter containing the names of "eight railways which have been constructed, or are in course of construction under certificates granted by the Railway Department of the Board of Trade, under the provisions of the Railways Construction Facilities Act, 1864." Of these eight railways, the author can learn nothing of Nos. 1, 2, 4, 7, and 8. As regards No. 3, the Secretary of that railway writes, that "so long a time having elapsed since the railway was constructed, it is doubtful if I can find the papers"; the only information sent was that the line is 6 miles 5 furlongs long, and cost "with extras" (whatever that may mean) 14,400*l.*, or 2173*l.* per mile. Of No. 6, the Engineer writes, "The portion of this railway authorised by the Railways Construction Facilities Act has not yet been constructed"; and of No. 5, the only one the author is in a position to name, the Secretary writes, "The Llanelly and Mynydd Mawr Railway is a single line with sidings, and cost with land and compensation 80,000*l.* It was made under

an Act of Parliament obtained in 1873." The length of this line is $12\frac{1}{2}$ miles, the gauge, 4 feet $8\frac{1}{2}$ inches, and the cost per mile, 6400*l.* Thus, as far as the author can ascertain, out of a list of eight railways supposed to have been constructed, or in course of construction under certificates granted by the Board of Trade, two only have been made, and one of these was actually constructed under an Act of Parliament obtained in the ordinary manner! The conclusion, therefore, forces itself upon one's mind that there is something more unpalatable to the public taste in applying for a certificate from the Board of Trade than in the procedure necessary for obtaining an Act of Parliament; and we therefore need, as already stated, greater facilities than we now possess for power to construct light railways.

There is at the present time a movement on foot for the development of steam tramroads, which may very properly be called light railways. This does not mean the ordinary *street* tramways, such as those which are laid throughout the suburbs of London and other large towns; but those carried across country, or along the waste space of open roads, of which there are already some few, either opened or in course of construction; although so far as regards parliamentary and preliminary expenses, such lines have cost just as much as ordinary lines of railway, in most cases a special Act of Parliament having been obtained.

The cost of an unopposed Bill in Parliament is about 600*l.*, whilst the fee for a Board of Trade Certificate is 10*l.*, and the difference between the sums, viz. 590*l.*, appears to be the only saving in expense, where the latter method is adopted, the preparation and deposit of Plans, Sections, Estimates, Books of Reference, &c., being the same in both cases.

Before proceeding further it will be well to see if a proper definition can be given of the term "light railways," and for this purpose one cannot do better than quote the words of a brother engineer, Sir Douglas Fox, M. Inst. C.E., viz. "These being either branches from existing main lines, or intended for districts requiring the development of their traffic, should be constructed in a thoroughly substantial and durable manner, equal in their details as to quality, to the best main lines, but with every part made only of such strength as to carry loads represented by the rule, that no pair of wheels should be allowed to have more than six tons upon it; this would enable these lines to carry the rolling stock of all other railways of a similar gauge, with the exception only of the locomotive."* The author suggests but one alteration in the above definition, and

* 'Minutes of Proceedings of the Institution of Civil Engineers,' vol. xxvi., p. 49.

that is, to substitute a load of eight tons in place of six upon a pair of wheels. Such lines of railway should follow, as nearly as possible, the natural surface of the ground, wherever the gradients will permit, avoiding, where practicable, all heavy works, such as deep cuttings, high embankments, tunnels, expensive bridges, &c., and crossing all public roads on the level, unless compelled by Law to do otherwise; and in *no instance* making a break of gauge, where it is proposed to bring traffic off or on to an existing or main line of railway. The maximum speed should be limited to 25 miles per hour, except at public road crossings, where it should never exceed eight.

It may be of interest to give a short description of a light railway, which the author believes was one of the first made in this country, and he cannot do better than quote the succinct and graphic description of the "Wotton Tramway" given by Dr. Pole, the Honorary Secretary of the Institution of Civil Engineers, who says: "One of the best examples of a light railway on the standard gauge was one laid down by the Duke of Buckingham on his estate near Wotton, a few miles from Aylesbury. The Duke, conceiving that many benefits would arise from extending railway communication through his estate, undertook to make a line from Quainton Road Station, on the Aylesbury and Buckingham Railway, to a place called Brill, about six or seven miles to the west, with a branch to Wotton, one of His Grace's residences. He entrusted the construction to Messrs. Lawford and Haughton, engineers, of Westminster, and the line was opened in the early part of 1871. It was called the 'Wotton Tramway,' but why this term was used is not clear, as it was as properly a railway as any other line in the kingdom. It followed pretty nearly the surface of the land, having gradients in some places as steep as 1 in 50, and curves of occasionally 12 chains radius; the rails (wrought iron) weighed 30 lbs. per yard, bridge section, screwed down with fang-bolts to longitudinal sleepers 6 inches by 6 inches, with cross ties at every 12 feet. There were no stations, but at each road-crossing was a siding for trucks; the entire cost, exclusive of land, was 1400*l.* per mile. The goods traffic consisted of coal, manure, road-metal, and general goods, inwards; of hay, straw, grain, timber, bark, and agricultural produce generally, and of cattle, both ways; there was also a coaching traffic of passengers and milk. The trucks were of the ordinary kind borrowed from the adjoining railways, they were drawn at a speed of five to eight miles per hour by a special engine weighing from 10 to 12 tons. It need hardly be said that the Duke, though no doubt he was anxious enough to reduce the outlay, did not commit the folly

of altering the gauge."* To this condensed but correct account of the Wotton Tramway it may be remarked that when the idea was first conceived, it was intended to work it entirely with horse-haulage, and it was so worked for the first year, but when the Duke was convinced that steam-haulage would be more economical than horse-power he wisely adopted the use of locomotives, with the result that the train mile is now worked at *8d.* as against 1*s.* On account of horse-haulage having been originally contemplated the peculiar form of permanent way was adopted; had the Duke intended at first to use steam he would, no doubt, have had a heavier rail on transverse sleepers; the longitudinal sleeper system had the advantage in prime cost, and was better adapted for horse traffic, although it has disadvantages arising from the timber being liable to warp and crack in hot weather, and that this form of permanent way is not so good for drainage purposes. It must be added that whenever the permanent way requires renewing the Duke has, since his return from India, used 8 inch by 4 inch longitudinals and steel-topped rails of the same section, but weighing 32 lbs. per yard. The maintenance of this line, exclusive of renewals, costs from 25*l.* to 30*l.* per mile per annum, and the traffic results of 1887 were 12,295 tons of general goods and minerals, 81,572 gallons of milk, 6072 passengers, together with sundry parcels and light goods, the two latter realising about 40*l.*; the engine miles run during the year were 8750. The passenger traffic realised 151*l.* 15*s.* 9*d.*

The manager of the Wotton Tramway states that the line on this estate is so conveniently situated as regards some of the farms, that grain, hay, straw, &c., can be carried from the farm-yard, on a man's back, into the railway trucks standing in the sidings.

It will be observed that the question of break of gauge has already been referred to. It is not desired to provoke a discussion on this much-vexed question, which has been well and ably argued in other places, but light railways of the standard gauge and those involving a break of gauge are so intimately connected together, that its introduction into the present paper cannot well be avoided. It may be gathered from what has already been said that the author is strongly opposed to break of gauge, and he would not on any account advise that a light or cheap railway should be made of any gauge other than that of the line with which it is proposed to be worked in conjunction. He is aware that some engineers in this country have adopted a gauge different to the standard gauge, and it would be inter-

* *Vide* 'Minutes of Proceedings of the Institution of Civil Engineers,' vol. xxxv., p. 432.

esting to know from those engineers whether such lines pay any dividend. As regards the Festiniog Railway, the gauge of which the author believes to be 2 feet, there is presented an instance of a line, *per se*, having no connection with any existing railway; and therefore the question of the expense of trans-shipment is not likely to arise. Sir George Bruce, President of the Institution of Civil Engineers, speaking at a discussion in the early part of 1879 on "Railway Construction in South Australia," said that, "having made railways of all kinds, he did not think there was a penny saved by making a 3 foot 6 inch gauge, as compared with the 4 foot 8½ inch gauge,"* in which opinion the author cordially agrees with him. Mr. Price Williams went further, and said that by taking maintenance and renewals into account, it was cheaper to make a 5 foot 3 inch gauge railway than one of a 3 foot 6 inch gauge.† On the other hand, the author would quote an instance of the actual difference of the cost of construction of a double line of mixed gauge railway, as against a double line of narrow gauge railway, the two gauges being respectively 7 foot ¼ inch and 4 foot 8½ inch; this question of cost was gone into by the author and others during the construction of the West London Extension Railway, 4½ miles of which were constructed on what is technically known as the mixed gauge principle. This extra cost amounted to 24,800*l*., or 5510*l*. per mile (exclusive of the cost of 2½ acres of building land), the whole of which was borne by the Great Western Railway Company, in accordance with the parliamentary powers, but the curious outcome of all this extra expense was that the broad gauge was *never used at all* for passengers except on one occasion, and then only for the removal of some troops from Victoria Station to Windsor; but it was used for some time between the Great Western Railway at North Pole Junction to carry coals, minerals, &c., to the Dock at Chelsea, *viâ* Addison Road, Kensington; but early in 1876 the broad gauge rail was entirely removed and is now a thing of the past, so far as the West London Extension Railway is concerned. There is still one other matter connected with this gauge question which should be mentioned, especially as it is probably not generally known to the present generation, viz. the case of the Eastern Counties Railway, now better known as the Great Eastern Railway, for which an Act of Parliament was obtained in 1836, at which time there was no Gauge Act in operation, and engineers therefore made their lines of railway of whatever gauge they pleased. The then chief engineer of that line

* *Vide* 'Minutes of Proceedings of the Institution of Civil Engineers,' vol. lvi., p. 75.

† Op. cit., vol. xxxv., p. 341.

recommended a 5 foot 6 inch gauge, afterwards reduced to 5 feet, and to this latter gauge the line was actually constructed as far as Colchester, a distance of 51 miles, to which must be added a further length of 29 miles, being part of the Cambridge branch from Stratford to Bishops Stortford, making a total length of 80 miles of double road; the argument then made use of being that the 4 foot 8½ inch gauge was too narrow for the machinery of the locomotive, and that by adopting the 5-foot gauge more room would be obtained for both machinery and boiler space. Mr. Robert Stephenson, however, who was then engineer to the Cambridge line, foresaw that if the 5-foot gauge was allowed to remain, all the Eastern Counties district would be cut off from actual railway connection with the rest of England; he therefore recommended that before the lines to Colchester and Bishops Stortford were carried any further, the gauge of both rails and rolling stock should be altered to 4 feet 8½ inches, and this was actually done in less than one month in 1844; but now comes the strange part of the story, viz. that in carrying out these alterations it was not found necessary to make any material change, either for the machinery or boiler space of the locomotives. The author has endeavoured to find some published account of this work, but failing in that, an application was made to Mr. W. P. Marshall, M. Inst. C.E., who, assisted by Mr. G. Berkley, carried out this work under Mr. Robert Stephenson. The following is an extract from Mr. Marshall's letters to the author of the 8th and 10th August last: "I do not know of any account of this work having been published; there was no difficulty in altering the rolling stock generally, the carriages and wagons only requiring each wheel being pressed 1¾ inches further on to the axle, by turning down the axle collars accordingly; most of the locomotives required little more alteration; in some (but only in a small part) of them the valve motion was slightly altered, and I think there were some new axles. The traffic was worked single line on the 5-foot gauge, whilst the other line was altered to 4 feet 8½ inches by shifting the inner rail, and then the second line was worked single 4 feet 8½ inches gauge, whilst the other was similarly altered."

The whole of the above alterations were carried out, so far as can be ascertained—and to the best of the recollection of the author, who, from time to time was on the line—without a single accident and without in any way interfering with the daily traffic of 80 miles of railway!—a most creditable performance both to the Engineering and Traffic Departments. It should also be mentioned that in 1872 the whole of the South Wales Railway was altered from the broad or 7-foot

gauge, to the 4 foot 8½ inch gauge, by the Great Western Railway Company's staff, in about one month; this included numerous other works, which were done at the same time, such as raising and extending platforms, &c. The actual length of line altered was 164 miles of double road and 76 miles—including sidings—of single road.

In confirmation of the foregoing may be added the following extract from the 'Life of George Stephenson,' by Samuel Smiles, 1858: "The same mistake (break of gauge) was committed on the Eastern Counties Railway, on which a gauge of 5 feet had been adopted; Mr. Braithwaite, the engineer, being of opinion that an increase of 3½ inches in the width of his line would give him better space for the machinery of his locomotive, but when the Cambridge Extension of the same line was formed, which was to work into the narrow gauge system of the Midland Railway, Mr. Robert Stephenson, its new engineer, strongly recommended the Directors of the Eastern Counties Railway to alter their gauge accordingly, for the purpose of securing uniformity, and they wisely adopted his recommendation. Mr. Braithwaite himself afterwards justified the wisdom of this step, and stated that he considered the narrow gauge infinitely superior to any other, more especially for passenger traffic."

In the obituary memoir of Mr. John Braithwaite, vol. xxxi., p. 209, of the 'Minutes of Proceedings of the Institution of Civil Engineers,' the change of gauge of the Eastern Counties Railway is mentioned, and it is there stated that "the works were made wide enough for a 7-foot gauge"; but this wants confirmation—the author was often on the line during construction, and has no recollection that such was the case—moreover, the bridges seem to negative the suggestion of the works having ever been wider than necessary for a 5-foot gauge.

The author would now draw attention to the Report of the Commission on the Depression of Trade in which was suggested that it would be a very good thing for the agricultural districts of this country, if a system of road tramways or light railways could be adopted, so as to feed the main lines of railways with the produce collected in the various localities.

Farming or agricultural districts would be made profitable if they sent to market their produce in competition with the large supplies which are daily brought from the Continent—and it is only by a system of communication with our main lines of railway that such produce could be collected quickly enough to preserve the requisite freshness of vegetables, flowers, meat, eggs, butter, and all goods of a perishable nature. It may be asked, would not such a plan as this be further promoted if the local authorities paid subsidies to the tramways or light

railways? Because their very existence would surely add to the rentals of farms in the districts served, which would otherwise probably be thrown out of cultivation for want of cheap and easy facilities of transport.

Another point that comes prominently before us in connection with this subject is that of the Rolling Stock for Light Railways; there is no doubt that some of the goods trucks, cattle wagons, &c., are much too heavy for the load they carry; for instance, some railway trucks weigh from five to seven tons, and carry only six to eight tons each load. An American engineer, who has paid much attention to this subject, and investigated the average freight traffic of some of our principal railways, says "that for every 1000 tons of paying load we are hauling 600 tons of superfluous dead weight; and he illustrates his argument with the old story of the man and the donkey going to the mill with the bag of corn, the corn on one side and a stone on the other to balance it; why should not the man dispense with the stone and put half the corn on each side? and the answer is, because his grandfather did not do so! This is the case with our railways to-day, and our farmers and manufacturers have to pay for carrying the stone as well as the corn. The remedy is to take the stone out of the corn bag, to do away with dead weight, and adopt more modern appliances upon the railways. It costs as much to haul a ton of dead weight a mile as it costs to haul a ton of paying load." It would require careful consideration to say what these modern appliances should be, but the authority quoted is evidently hinting at the introduction of "bogie" wagons, and he goes on to say that "from the moment the first bogie wagon is introduced, the net earnings will commence increasing on our English railways." One great advantage in the use of the bogie on light railways is, that wagons or cars so built can turn the sharpest corners without tearing the rails in their progress, and they are in every respect less injurious to the road-bed on which they run. In America such bogie wagons are stated to weigh $9\frac{1}{2}$ tons, and to carry 30 tons with a maximum capacity of 40 tons.*

* Since the foregoing was written, it has been stated in the daily journals, that the American engineer's suggestion of the use of the bogie truck in this country is about to become *un fait accompli*, as a freight car on this principle was exhibited and inspected on the 30th of August last at the St. Pancras goods station of the Midland Railway. This new truck weighs 10 tons, and has a carrying capacity of 30 tons, three times its own weight; it is 33 feet long, and runs on two bogie trucks of four wheels each, the centre of the wagon being supported by a tubular steel frame. During the inspection it was shown that this car could accommodate a 25-ton gun with perfect ease; the use of such cars would prove invaluable to our railways in general, and especially so to "light railways."

Early this year the author visited the Wolverton and Stony Stratford steam tramway, or light railway, which is in fact a combination of both, and there saw some double-bogie tramcars, 48 feet long, weighing 7 tons, and carrying as many as 134 passengers, or an additional load of say $9\frac{1}{2}$ tons. The gauge of this line is 3 feet 6 inches, the sharpest curve is 32 feet radius, and the steepest incline 1 in 18. The cost of working per train mile is one shilling. The length of the line from Wolverton to Stony Stratford is $2\frac{1}{2}$ miles, and thence to Deanshanger, with sidings, nearly 3 miles. The weight of the groove rail on the first part of this line is 61 lbs., and of the edge rail on the Deanshanger Extension, 41 lbs. per yard, the latter is single headed, Vignoles section; both are of steel. The line, after passing through Stony Stratford, is laid on the "waste" of the road, and cost 1250*l.* per mile, and would have been cheaper had it been made "in a ballast district."

Up to the present time the author believes there are only some nine or ten light or road railways at work or nearly completed in this country, and among these are the Wantage line, the Wisbech line, the Alford and Sutton, and the Stony Stratford lines—strictly speaking, these are road railways—and a fourth line between Lincoln and Brigg is now under construction. Besides these there are the Festiniog Railway (already alluded to), the Southwold Railway, and the Wotton Tramway. The Clevedon and Weston-super-Mare light railway is not yet completed, and an Act of Parliament has been obtained this session for a light railway or steam tramroad between Oxford and Aylesbury. It would be premature at present to speak further of this last-named line, which will absorb the Wotton Tramway, but as the author has, in conjunction with Mr. Arthur C. Pain, M. Inst. C.E., the honour of being engineer to this line, he trusts to have the pleasure of giving more information about it on a future occasion.

The author alluded to certain light railways in Russia, known as "Maltzeff" railways, in a discussion on Mr. Walton's excellent paper on "Railways for Rural and Undeveloped Districts," before the Civil and Mechanical Engineers' Society, on the 24th April, 1888, and said: "The only particulars of these lines I have, is that their cost of construction is barely one-fifth per mile of the cost of ordinary heavy lines, and that they pay an annual surplus profit of $3\frac{1}{4}$ per cent. on the cost of construction"; but since that date, the author has been in correspondence with Mr. John Michell, the British Consul at St. Petersburg, and the latter has most kindly supplied further information on this subject, as follows, viz.—"It would

appear from a description given in the Official Gazette in 1880 of the Maltzeff Railway, that the same runs to a great extent through the lands that formerly belonged to Mr. Maltzeff, and which are situated in the Briansk district of the Province of Orel, Jisdra district of the Province of Kaluga, and the Roslavl district of the Province of Smolensk. The railway is of narrow gauge and extends uninterruptedly over a distance of 150 versts, or 100 English miles, including several branches that lead from the main trunk line to outlying manufactories of various descriptions, as also to coal and iron mines. The rails are of a lighter description than those ordinarily used. The locomotives are of special construction; they are of high pressure (about twelve atmospheres) without tenders, very light, and have only four wheels. Their water supply is kept in two tanks, one on each side of the boiler, and the fuel, which is wood, is carried on the locomotive, an iron railing dividing it from the furnace. The cost of each locomotive did not exceed 700*l.* As the railway was constructed almost entirely for the transport of goods and materials of every description, the gradients and deflections (curves) of the line are greater than those adopted for railways on which there is much passenger traffic. The goods-trucks and carriages are of the usual type, though much lighter, as are also the carriages for passengers, which are only of two classes, second and third. The construction of the 70 versts (47 miles) section of the railway from Raditzi to Rudenova, together with 7 locomotives and 100 cars and trucks, cost about roubles 7000 per verst (about 700*l.*), and the maintenance (including pay of employés, &c.) did not exceed 600*l.* per month. Although the length of the whole line is, as above stated, 100 English miles, the railway passes in a direct line only through 47 miles, formerly constituting the Maltzeff property. The remaining length of the line is represented mainly by branch lines, and partly by that portion which extends outside the boundaries of the Maltzeff estate. The line is said to have repaid in 1880 nearly all cost of its construction. Since the above description was given in the Official Gazette of the Maltzeff Railway, the proprietor, Mr. Maltzeff, has died, and the whole estate with its numerous industrial establishments is in process of liquidation by the Government, to whom the property was largely mortgaged, owing to its mismanagement after the death of Mr. Maltzeff, who converted it into a shareholding concern a few years before his decease. These are all the details I am able to send you on the subject, and I exceedingly regret their scantiness."

In the 'Engineer' of 3rd August this year it is stated that

the average cost of a mile of railway in the United States is 6000*l.* per mile; in England we know that the average cost of the main lines is 40,000*l.* per mile, while a road or light railway can be constructed and equipped for from 4000*l.* to 5000*l.* per mile.

The Aylesbury Branch of the London and North-Western Railway, and the Aylesbury and Buckingham Railway, so far as works are concerned, may be taken as types of light railways, i.e. they are both 4 foot 8½ inch gauge single lines, with sidings and for the most part surface lines, but the permanent way is heavy and of the same character in all respects as the main lines of the country; the length of the former line is seven miles, and of the latter 12¼.

The Secretary of the Aylesbury and Buckingham Railway stated "that the cost of the line and stations was approximately about 12,300*l.* per mile."

In vol. lv., p. 388, of 'Minutes of Proceedings of the Institution of Civil Engineers,' there is an excellent article upon Lig. t or, as they are termed in France, Secondary Railways (Chemins de fer d'intérêt local), the perusal of which is strongly recommended to any one interested in the subject, and from which may be quoted one sentence, viz. "whenever it shall be necessary to construct special tracks the normal gauge of 4 feet 8½ inches should, save in exceptional cases, be adopted." The normal gauge in France is the same as our own; the writer of the above article gives all dimensions and details of such a railway, the total cost of which, equipment and all expenses included, he fixes at 75,000 francs per kilometer, or 4800*l.* per mile.

At Decazeville, in France, there is a light railway 12½ miles in length, with a chair and transverse sleeper road and a 32-lb. rail, the average speed of the trains is 9½ miles per hour, the cost of the permanent way was 766*l.* per mile, the gauge is not given, but is probably 4 feet 8½ inches. This line was worked with horses till 1870, when locomotives were substituted, showing thereby a clear saving of one-third in working expenses, the same result as that arrived at in the case of the Wotton Tramway.

The Broelthal Railway, constructed in a district unable to support an ordinary railway, is a light railway laid down on the existing roads of the district; it is 20 miles long, and was constructed in 1864, the gauge is 4 feet 8½ inches, and the cost of construction, including equipment, 3231*l.* per mile.

In Hungary, where all railways are on the 4 feet 8½ inch gauge, they are divided into two classes, viz. the first class for important main lines, and the second class for poorer districts, which

if traffic increased could be converted into first class railways. There were in Hungary a few years back about 300 miles of second class railways at work, the average cost of construction of 162 miles having been 6450*l.* per mile; the rails were Vignoles, or single-headed section, $47\frac{1}{2}$ lbs. per yard; the abovenamed cost per mile must not be taken as a precedent of the cost of these railways, as when they were made, iron, materials, and labour were very expensive. They could probably be constructed now for 5000*l.* per mile, or rather less. In addition to the 300 miles of light railway two other lines have also been made in Hungary, each about 29 miles long; one is called the Valkany and Perjamos Railway, and cost 4073*l.* per mile, the other is the Vojtek and Bogsan Railway, and cost 4295*l.* per mile. In order to encourage the construction of these light railways in Hungary the State remitted the duty and taxes on them for thirty years, besides allowing a reduction from the regulation weight of rails, size of sleepers, quantity of ballast, &c.; the details of construction of these two lines will be found in vol. xlvi., p. 282, 'Minutes of Proceedings of the Institution of Civil Engineers.'

There is an excellent paper on the 'Construction and Equipment of Railways in Newly Developed Countries,' by Mr. J. R. Mosse, M. Inst. C.E., in vol. lxxxv., p. 86, of 'Minutes of Proceedings of the Institution of Civil Engineers,' the perusal of which is strongly recommended to any one interested in the subject of light or ordinary railways, and especially to the younger members of the profession.

There are also two interesting works on very narrow gauge railways which will repay a perusal, viz. 'Railways, or No Railways,' by the late Mr. R. F. Fairlie, C.E., published in 1872, and 'Remunerative Railways in New Countries,' by Mr. R. C. Rapier, M. Inst. C.E., published in 1878.

In Canada the cost of ordinary or 4 feet $8\frac{1}{2}$ inches gauge lines has been about 8000*l.* per mile, and of light or 3 feet 6 inches gauge lines just half of that amount; of this latter gauge some hundred miles have been constructed and successfully worked.

The author submits that enough has been adduced to show that light railways can be constructed substantially, and at the same time made to pay if they are properly worked, at all events this has been accomplished in foreign countries, and therefore why should not the same result be achieved here? It must be noted that on some of the lines referred to by the author "State" subsidies have been given, an artificial stimulus which can be scarcely looked for in this country, seeing that our Government has never interfered in railway matters so far as finance is concerned.

There is also no doubt existing a certain amount of dislike amongst the managers of our large arterial lines to have the working of short branch lines thrust upon them until it can be satisfactorily proved that they will bring traffic on to, and feed the parent lines, without which evidence they will not take to them *con amore*, if at all.

Again, as already stated, greater facilities than the Board of Trade can at present give are wanted for power to construct such lines; there is doubtless something far more satisfactory in having an Act of Parliament in your pocket than a Board of Trade Certificate, and it is to be feared that the latter is generally looked upon as a sort of cheap substitute for the former, and sneered at accordingly; possibly that is one reason why so few lines have been constructed under certificates, and the author, speaking as an engineer, does not think the amount of work or trouble is much lightened by them; financially, they may give a little relief, but in the end the saving effected does not amount to much.

In conclusion, the author fears that the task he has undertaken has been somewhat imperfectly carried out, and for this reason, that shortly after accepting the President's invitation to write this paper, his *modus operandi* was to find out, as far as possible, all that had been written and said before on the subject, and with this view he consulted many previously recorded opinions, and chiefly those to be found in the 'Minutes of Proceedings of the Institution of Civil Engineers,' and the conclusion he came to was that there was really little or nothing left for him to say; however, having once taken the matter up he was determined to persevere in it with a result which he trusts has not been entirely unsuccessful, and hopes further that the subject of this paper may be again considered and properly grappled with by men of power and position who can bring it to the front, and thereby at least give the question of "light railways" the full and *bonâ fide* trial it deserves.

An extract from the *Times* of 8th September, 1888, Meeting of the British Association at Bath, is quoted:—

"Mr. Sellon said that the present tramways system might be modified so as to become a feeder to main lines of railway for every description of goods and merchandise as well as passengers. Lines could be laid on the waste part of country roads at a moderate cost. He also pointed out the necessity for reform in private Bill legislation, as there was too much expense in the introduction of a scheme prior to consideration, a mutilated Bill being often accepted by the promoters in consideration of the money already expended. He was strongly against the construction of any light railway or tramway

involving a break of gauge. The Irish Tramway Act of 1883 was a failure, because the gauge was fixed at 3 feet.

"Mr. Shelford said he thought the great difficulty in the way of light railways in this country was the want of legislation. At this moment farmers were unable to obtain light railways because Parliament had not afforded the legislation in order to accommodate them. There were no means available at present in this country of obtaining power to make a really light railway. In our Colonies and elsewhere there was a wide field for those lines of railway."

NOTE.—The extension of light railways, branch lines, and road railways in Germany, Austria Hungary, Holland, and Luxemburg, has left this country *far behind.* There were on the 1*st January* 1888, in the above-named countries: 1. Under 5 miles in length, 85 *lines* extending over 206 miles. 2. Under 10 miles, but over 5 miles, 33 *lines*, total length 242 miles. 3. Over 10 miles in length, 46 *lines*, total length 1173 miles; in all 164 *lines*, extending over 1621 English miles, worked by 664 locomotives.

DISCUSSION.

On the motion of the President a vote of thanks to Mr. Lawford for his paper was unanimously passed.

Mr. ARTHUR C. PAIN said he had constructed three railways under the Light Railway Clauses of the Regulation of Railways Act, namely the Culm Valley Line, 7 miles in length, the Swindon and Highworth, 6 miles, and the Southwold, 9 miles. The first two were 4 feet 8½ inches, and the last 3 feet gauge. The first two were purchased by the Great Western Company, but in the process of absorption, the shareholders did not get very much. Failures were sometimes as useful as successes, but financially neither of those lines paid anything to the ordinary shareholders, and he would relate as briefly as possible why they did not do so. It was in a great measure owing to the want of proper legislation. The Light Railway Clauses, so called, were to enable persons promoting lines and limiting the speed to 25 miles an hour, to construct such lines on an economical scale, and yet have the approval of the Board of Trade officials. But they were still subject to the various Railway Acts, and directly they began to construct under those Acts, they incurred considerable and unnecessary expenses. Then they had to get the money to make the railway, and even when they got it they found themselves stopped by landowners, who, having received them at first with open arms, afterwards said, "We are very, very sorry our estates are under trust, and my trustees say they must get the highest price they can." The long and short of it was they had to pay through the nose for everything—not only for land, but for accommodation works;

it was always said that they managed to go through the best lands of the farm. Then if the line was worked by a parent company, they had to get their officials to approve. Those officials were accustomed to everything being on a heavy scale, and the result was they were obliged to spend such a large amount of capital that the poor shareholders' hopes were soon gone.

Now how was this state of things to be amended? He believed it was only to be done by legislation, which he thought should take the form, that under the powers of the new County Council it should be competent to promoters to apply to the Council of those counties affected, for authorisation of such secondary railways as might be required, and he believed that if care was taken that the scale of fees was not too extravagant, powers would be obtained that would answer all practical purposes. He was not of course assuming a case where the lines were fighting, but of lines where the general feeling of the inhabitants was in their favour, and against which there was no serious opposition. Now if the County Councils, in addition to having the necessary authority to grant powers to make these lines, were also to have the power to charge the parishes with a rate for payment of the interest on the expenditure in their construction, he thought they would have a very valuable help towards the development of these lines, and he believed unless some *modus vivendi* of that kind could be adopted they would not see any large extension of branch lines. Mr. Williamson, he thought, would agree that the number of cases where the lines could be put on the road were very few as compared with those in which it would be more advantageous to carry them right across country. Mr. Lawford mentioned the question of bogie wagons. Such wagons with 30 tons load might be all right on main lines, but he should question their advantage on branch lines.

As regards the Southwold Railway, he had managed it since 1879, and could therefore speak from some experience, and he should not hesitate to say to the promoters, "Don't be frightened on the question of working the line yourselves," as he believed if they were to work the line themselves, and not rush into the arms of the parent company, they would do much better. On the question of gauge he differed from Mr. Lawford. He thought it should be left to the engineer. He was perfectly satisfied that a narrow gauge line could be both made and worked for less money than a 4 feet 8½ inches gauge, but he was not prepared to say that under all circumstances a narrow gauge would be the best. The Southwold Line were parties to the Railway Clearing House, and had

arrangements with all the principal companies; say, for instance, if the rate was 5s. to any station; on the division of that money they got 6*d.* for the transfer, and in no case that he knew of had anything extra been added to the rate to cover this. Therefore, the public did not suffer. The transfer of goods might practically be said to cost them nothing, but when they come to the question of transferring coal, tiles, and all things of that kind, the cost of transfer varied from 4*d.* to 6*d.* For slates and tiles, which were rather troublesome things to handle, they charged 6*d.*, and for coal and coke they came down to 4*d.*, but they had no quantity to deal with, such as would justify the erection of elaborate machinery, as in the case of a very heavy traffic. With regard to goods, there were some advantages in having a break of gauge, as they ran the trucks quite full. On the other hand the fish traffic, which always came in at the last moment, had to be transferred, and they were sometimes pushed to do it in time, whereas if the line were of the ordinary gauge, they would be able to run it right through. The Blything Union Workhouse was 3 miles from Halesworth Station, and then Wenhasten Station $2\frac{1}{2}$ miles from Halesworth. They contracted for some hundreds of tons of coal every year, and it paid the contractor to carry it over their railway, and then cart it $\frac{3}{4}$ of a mile, rather than cart it all the way by road for the 3 miles. That was a proof of many years standing that transfer was no practical objection.

Mr. R. PRICE-WILLIAMS said it would occupy too long a time to enter into a discussion with Mr. Pain to prove the unsoundness of his argument that there was no loss on the transhipment of coal; he would merely state from his own experience there was a loss of from 9*d.* to 1*s.* a ton from each operation. He had hoped that the vexed question of broad and narrow gauges had now been finally disposed of, and that there was a general agreement in the profession that the evils attendant upon a break of gauge far outweighed any advantage. His experience of narrow gauge lines during his recent visits to New Zealand and South Australia certainly confirmed the adverse opinions which had been expressed about narrow gauge lines, generally any slight lowering in cost of construction being far outbalanced by the additional cost of repairs and renewals, both of the roadway and rolling stock. He entirely agreed with Mr. Lawford, that no real advance in light railway construction would be made until we obtained legislative powers in harmony with the requirements, and got the big railway companies to realise the fact that the introduction of these subsidiary lines would, in the course of time, prove to be a fruitful source of revenue to them. He must admit that his

experience with regard to the attitude of the big railway companies to light railways had been very disappointing. He knew of a large district at the present moment in this country of at least 18 miles long by 10 miles wide, through which the old mail coach road passed, but which was entirely unserved by a railway, and where the great railway company, which traversed the northern part of the county, offered no inducement to the construction of a light railway, such as would afford the farmers the cheap transit they required to enable them to obtain a market for their agricultural produce in the neighbouring towns, and—what was to them as essential for maintaining the productiveness of their farms—the means of bringing back from those towns the rich manures, artificial and otherwise, so necessary for the proper development of the agricultural resources of the district.

He hoped that the new local government boards would enable this and many other large agricultural districts, at present without any railway accommodation, to provide light and inexpensive railways such as proposed by the author of the paper. His experience of light railways had been chiefly in Ireland, and he quite agreed with Mr. Lawford that the working of the Irish Light Railway Act of 1883 had proved to be a complete and absolute failure. It was intended to be the first step towards local legislation in that country, and it gives powers to the different Baronies to sanction the construction of light railways in any district, such sanction requiring only the approval of the Lord Lieutenant in Council, so that "an Order in Council," for the construction of a particular light railway should hereby have all the force of an Act of Parliament; but he was bound to say that in the case of most of the light railways he had to do with as engineer or joint engineer with his colleague Mr. Price, he had found where, as frequently happened, the line passed through two or three Baronies, the grand juries of the different Baronies (who constituted the tribunal before which the promoters had to appear) very often took opposite views, and in one particular case, where he had to appear as a witness before four different grand juries, the opposition of one of them was sufficient to upset the whole undertaking; in fact, the expense of having to appear by counsel before four grand juries, far exceeded what would have resulted if the promoters had appeared before Parliamentary Committees of both Houses.

As regards the great need of light railways for the large districts at present unprovided with railway accommodation, he might mention that the late Mr. Vignoles, in his presidential address, drew attention to a fact which he remembered im-

pressed him greatly at the time, viz. that there were 160,000 miles of metalled roads and highways in this country which, although in some cases ran parallel with railways, still for the most part served as the only channel for the conveyance of the present traffic in rural districts; and he ventured to think that upon the cess or side-space of many of these roads, light and cheap railways might with great advantage be constructed in this country, just in the same way as is now contemplated in Ireland. He had long been of opinion that, both as regards roads and railways, these great highways of the nation should become the property of the State; and he looked hopefully to the time, not very far distant, when gigantic monopolies, such as our railways have become, should cease to be what they now were, viz. commercial and speculative undertakings, carried on primarily for the special benefit and advantage of the shareholders, and not for the advantage, as they should be, of the nation at large. He did not advocate State management, nor did he consider that State management was necessarily involved in State ownership. They had already in the admirable executive of the Clearing-house, that which, together with representatives to be selected from the new local government board and with the new railway commission, would supply all that was needed to continue the railway administration in such a way as would, by large and judicious reductions in the existing tariffs, tend to give a great impetus to the trade of this country, and more especially to develop the vast agricultural resources which, chiefly owing to the absence of cheap tariff rates, have been too long neglected.

Mr. Wm. Shelford said he was present rather to support Mr. Lawford than to join in the discussion; but, since he had been called upon, he would be happy to say a few words. His own personal experience in the construction of light railways had been confined to the Colonies, still as he had made tramways in this country and also constructed heavy railways, he was therefore able to say that the whole question teemed with interest, and it was difficult to select points upon which to speak in the limited time at one's disposal. He had been over Mr. Lawford's Wotton Tramway, constructed for the Duke of Buckingham. Some years ago he took great interest in this question. One line which he was projecting attracted attention at the time, as it was through that line that the Select Committee of the House of Lords on Steam Tramways was appointed, and that line was made a special object of attack by Lord Redesdale. The Committee took evidence by Mr. (now Sir James) Allport, who suggested that the steam tramways, if constructed, should be of a narrow gauge. He was followed by Mr. Oakley,

of the Great Northern, who fixed as a desirable gauge for those feeders 2 feet or 2 feet 6 inches. Sir James Allport was one of the Commissioners who had just reported on Irish Public Works, and they had attributed the failure of the Irish Tramways Act to the gauge being 3 feet. The apparent inconsistency was easily explained by what every engineer knew, that they must find out in each case what they had to do, and not draw moral conclusions too rapidly. He thought that the conditions in the Colonies and in Ireland were in many cases totally inapplicable to England. He scarcely ventured to touch upon that knotty point, the break of gauge; but he thought what they had to do here was to avoid break of bulk rather than break of gauge. If to relieve the agricultural depression they had to make light railways, it was sometimes very important that the produce should be brought to market without break of bulk. Mr. Sellon read a paper at the British Association in which he described tramways and also showed a model of a pair of wheels adapted to run on road or tramway. They were not the first of the kind, but they were ingenious, and showed how tramway trucks might run into a farm from the tramway and vice versa. In cases where such trucks were much wanted it appeared to him that if they were loaded up at the farm and drawn to the tramway, and thence along it to the junction with the main line, the bulk must be broken there, because such trucks could not yet travel on the main line. Why not therefore break the gauge? He knew for a fact that they could get a line more cheaply constructed if they had a narrow gauge. It might not be much cheaper, but where the tramway was made by private or independent parties and money was scarce, any saving was important. He also knew that in narrow gauge tramways the rolling stock was more handy, it was less open to the objection of frightening horses, and it possessed one great advantage in the eyes of the Board of Trade, that a railway company could not run its heavy main line engines upon it as on a branch line. Taking another class of cases in Ireland or the Colonies, communication was so scarce that a railway truck might be brought only to a station and yet give very great convenience to a farmer. If that was the sort of accommodation they had to give, let them by no means break the gauge. As a general view he could really conceive nothing more perfect, for the highly cultivated portion of this country and for the class of line they were talking of, than the plan adopted by the Great Eastern Railway Company in the Fens of Cambridgeshire, where after the people had tried to get a railway but failed, the Great Eastern had constructed a steam tramway alongside the road, somewhat similar to the Duke of Buckingham's tramway but nearer the road, and notwithstand-

ing the competition of a canal, that tramway had been a success. It was worked by the Great Eastern he believed with entire satisfaction to that Company and to the district, so much so that he understood they intended to extend the system. It appeared to him that if the great companies would look the position fairly in the face and recognise the agricultural depression, and see how far they could remedy it, they would assist the extension of tramways in the country. In such a case the companies would do well to use their normal gauge, and run their own goods trucks along the light railway or tramway, and if they eventually found that the farmers wanted the trucks drawn into their fields, then they must put on special trucks adapted for the purpose. But they might wait for the millennium for that. In conclusion, he would say that in America, especially in the great wheat-growing districts of the States and in North Western Canada, the question of cheap transit and light railways had been more closely studied than anywhere else in the world, and the standard gauge of 4 feet 8½ inches had been adopted. For the wheat traffic they were now using 30 (American) ton trucks for carrying heavy loads, but they were totally usuited for the short traffic of this country. They had reduced the railway to a skeleton and they had worked out the essential part of a railway as a means of transit, apart altogether from the adjuncts which to a large extent ruled the cost of construction here.

Mr. J. B. Walton said he had had occasion to study this subject very closely for many years past. In conjunction with Mr. Pain he was responsible for the narrow gauge adopted for the Southwold Railway. At the time he was somewhat convinced against his will, but as money was limited he consented to waive his objection. Looking at it now he thought the adoption of the 3-feet gauge was a great mistake. All he had had to do with the line since its construction was to study the half-yearly reports, which were not very pleasant reading. In March last he read a paper before the Civil and Mechanical Engineers' Society on "Railways for Rural and Undeveloped Districts," in the discussion of which both Mr. Walmisley and Mr. Lawford took part. The conclusions he came to as embodied in that paper were, that all such railways should be constructed on the ordinary 4 ft. 8½ in. gauge, with a permanent way sufficiently strong to take the main line stock at reduced speeds. He quite agreed with Mr. Shelford that if they waited for the existing companies to provide accommodation for the outlying districts, they might wait till the millennium, although they were glad enough to induce other people to undertake the expenditure. The question then arose, Could a

district be found which would at its own expense take up the construction of one of these railways? In the paper to which he referred, he threw out a suggestion that when the County Councils were established they would be the most fitting bodies to take the initiative, and he thought that if the matter was fairly and fully brought before them they might be inclined to do so. He further suggested that they should have power of levying a rate to aid the construction of such line in the district over which they had control. He quite thought that in these undeveloped districts, notwithstanding all that had been said to the contrary, railways might be worked at a profit. He had gone into the question of expenditure very closely and believed that a railway could be made at the cost of 4000*l.* to 5000*l.* per mile, and he should not be afraid of undertaking the cost of working it. If the promoters of these lines, instead of rushing into the arms of existing companies, would boldly grapple with the question, they would find they could work them to more advantage themselves. With traffic receipts at the rate of 5*l.* to 6*l.* a week, the results would show a very fair margin of profit. Mr. Lawford had dealt with many matters of ancient history, he (Mr. Walton) preferred to deal with the present. His opinion was they should stick to the normal gauge as far as possible, as experience had shown there was nothing to be gained by a narrow gauge. He should be happy to send a copy of his paper to all members who were interested in the subject.

Mr. W. B. Myers said his chief business was connected with the construction of very heavy railways, but he had had to consider the subject of light railways several times, and he was very glad to hear some gentlemen present not condemn break of gauge. He was decidedly of opinion that in some circumstances break of gauge might, in saving of material, make the difference between a railway which could not possibly pay and one which might pay. The author of the paper gave some particulars with regard to locomotive expenses per train mile. They were very interesting, and he wished they could have the other expenses per train mile. Of course the average cost of working per train mile for railways was 2*s.* or 2*s.* 6*d.* If light railways could be worked for 1*s.*, or perhaps 1*s.* 6*d.*, it made all the difference between getting a profit or a loss. The narrow gauge greatly reduced the working expenses, in the reduction of the weight of the rolling stock. Mr. Shelford and Mr. Pain made some remarks with regard to the narrow gauge with which he quite agreed, and he also agreed with Mr. Price-Williams that the roads should be used for these railways whenever possible.

Mr. Stephen Sellon said, many remarks had been made

that he would much like to criticise, but time would, however, only permit him to condense his remarks and answer only the most salient points which had struck him in the discussion. He could not quite agree with Mr. Lawford in the remark that he did not look forward to Government assisting them in the construction of railways in England. He (Mr. Sellon) did not see why, if the Government could afford to give a guarantee in Ireland, it should not be given in England, where they required it just as much in some agricultural districts. With regard to the remarks made by Mr. Pain, as to landowners and their promises in the beginning to assist in giving their land, followed later on by the promoters suddenly awakening to the fact that the landowners' opinions had changed since the passing of the Act, and that ultimately the former were called upon to pay a large sum for land which they had expected for nothing—"Put not your trust in princes" would be the best advice he could give. Could Mr. Pain tell of any light railway ever made where the stock was subscribed in the district? As regards the alleged obstruction of the Board of Trade, he did not blame them as a body, for they had no discretionary powers, being bound up with red tape; otherwise he thought they would be more willing and able to do what it was hoped they would do. The inexperience of those who will join the County Councils would produce, he feared, a retrograde movement, as the whole routine must be gone through again. If they were composed of landowners, whom his experience told him they had had to fight, it was his opinion they would not be inclined to sink their own opinions. The roads as they stand were the present highways for traffic, and he did not see why they should not carry their light railways along the roads as far as they could. If they made a light railway across country to divert the traffic from its original source, it might be some time before people would care to take it along that route. He believed in course of time the railway companies would see the advantages of this; they were learning the lesson. On the Wolverton and Stony Stratford Steam Tramway they were seeing the advantage, and he believed they would see it still more in future. It was inconceivable to every person of natural common sense why railway companies should throw obstacles in the way of anything which must be a great feeder to them. With regard to Sir James Allport's opinions sometime ago as to the advantages of the narrow gauge question, he was very certain that they were not his opinions now, from what he had told him lately. As regards the question of breaking bulk, of course the particular model which he showed at the British Association was only a patent invention to overcome the disadvantages of its being a narrow gauge line along which they

could not take the railway trucks. They all appreciated the fact that there should not be a break of bulk, but let it be remembered by these means there was only one break of bulk. He (Mr. Sellon) was responsible for giving to Mr. Lawford the cost per train mile of working on the Wolverton Tramway; Mr. Myers said 1*s.* is a very low rate indeed, but when Mr. Lawford was speaking of the 1*s.* per train mile, Mr. Wilkinson turned round and said "I think you have put it rather high." He had put it high so that there should be no discussion about it. If Mr. Myers would look through 'Duncan's Manual,' he would find that the average cost of steam tramways had been about 8*d.*, and of horse tramways about 7*d.* or 6*d.* He believed he was right in saying that the Birmingham and Aston had been working their line for 8*d.* per train mile, and he hoped when they had had a little more experience in working the Wolverton line he should be able to show Mr. Myers that they were below 1*s.*

Mr. J. W. Grover said his experience had not been very great, but he was afraid the conclusion he came to was, that a light railway was a cheap railway, and a cheap railway as a rule was a bad railway. He was in the unfortunate position of having once written a paragraph advocating light railways. A few copies still existed in Westminster. The fact was that an engineer after all was but a trustee for others' money, and he had to try if he could get the unfortunate shareholders some return for their money. Take the Felixstowe Railway, in his opinion there never ought to have been a heavy railway made there; but the result had been that the railway not only had been of great benefit, but the promoters had been able to sell it to the parent company, and get back a very considerable portion of the share capital, though how much he did not know. It was his misfortune to have been connected with a railway where they had some difficulties to deal with, and it was his ambition to make a light railway; but when they came to the large companies they would not have anything to do with it as a light railway, and so it was made in the ordinary way, and the shareholders got a 4 per cent. guarantee. Then again they had this question to consider, where they had branches in the country, they had an engine under steam which only had perhaps four or five miles to run, and yet she was under steam all day, whereas if she ran twenty miles along the main line, she was doing some useful work. He must say, however, that he had listened with very considerable interest to Mr. Lawford's suggestion, re-echoed by Mr. Pain, that there should be a rate by the County Councils for the purpose of making these light railways. People said, "But the landowners should do something." He said "Granted; but is it right that

one landowner who happens to be in one position should have to sacrifice a great deal for the benefit of a great many others in the district."

Mr. C. H. Wilkinson said that two years ago he spent part of the summer at Felixstowe. He was so much impressed with the place that he almost came to the conclusion that a tramway would pay, and he knew of no more successful or rising watering-place. Mr. Grover probably did not know that the position of the railway there was almost unique. It was built almost entirely at the expense of Colonel Tomlin, a man who could afford to spend 150,000*l.* or 200,000*l.* and wait for the return. He built, in connection with the railway, a dock opposite the Harwich Dock, with the intention of compelling the Great Eastern to buy the line. He was in a position to stick to his ship, and the consequence was he got something like 159,000*l.* out of the Great Eastern for the railway and the dock. Mr. Grover, seemed to take a very pessimistic view of railways generally, but he did not agree with him that light railways could not be made to pay. He thought it was quite a moot point whether light railways could be made to pay in small sections of three or four miles, constructed on a different gauge, and worked by different companies; for the simple reason that the separate companies were so powerless to cope with the great trunk lines, that they were like children in the hands of giants. They had not the power to cope with the big lines, and therefore every advantage was taken of them by the latter, and their failure in so many instances brought about. It was a question of money; if they had sufficient money to build these lines so as to be independent of big railways, they would also be almost independent of gauge. At the same time he did not wish for a moment to say that he should support the break of gauge. He thoroughly believed in a uniform gauge; but admitted that even narrow gauge lines could be made to pay, provided they were of considerable length. It was absolutely impossible to run three or four miles of line at a profit, and have to repair their own engines and cars, which involved separate shops. Everybody knew that things done piecemeal in that way could not be done economcally. He did not say that it was impossible that they could pay, but that it would be very difficult to make them do so. What was wanted, he considered, was a great organisation or company backed by millions of capital. He knew that it would be difficult to get, but if it could be raised such a company would not only be in a position to pay the paltry 4 per cent. that many of the great lines now do no more than pay, but 10 per cent. on the moderate cost of construction, and there could be no doubt that these lines might be easily constructed at a cost of 4,000*l.* a mile.

Mr. FREDERICK G. BROWN said he had recently returned from Australia, after being engaged there ten or twelve years in the construction of light railways and tramways, and he was certainly rather surprised to hear that it was not possible to build similar lines here in such a manner as to make them pay. He regarded cheap light railway construction as an important factor in the solution of the existing agricultural depression difficulty here. There had been no difficulty in many outlandish places, where both labour and materials were more costly than here, in building substantial light lines at a cost of 5,000*l.* per mile, and even as low as half that in easy country; and he would point to the Brisbane and Sandgate Railway, in Queensland, passing through a sparsely populated district, yet paying 10 per cent. from its completion. With regard to the break of gauge question, he though the last speaker had hit the right nail on the head; it seemed more a question of length of subsidiary line than anything else. While short branches should obviously be of the same gauge as the trunk lines, with longer connecting systems the matter would be largely determined from the consideration as to whether the interest on the saving in capital expediture effected by adopting a narrower guage, exceeded or otherwise the cost of transhipment at the junctions. But in this country very good reason indeed would have to be adduced for any departure from the standard gauge, with its many advantages as to uniformity of rolling stock and equipment. He considered the 3 feet 6 inches, or, say the metre gauge, the narrowest practiable for ordinary light lines, and thought they would not be found much cheaper than the normal gauge under usual conditions; but in rough country a considerable economy could be effected by their adoption, as they permitted the use of much sharper curves. It was quite possible to operate a 25 mile per hour train service, over a light line with curves of minimum radius of 5 chains and ruling gradients of 1 in 40 or 50, which could scarcely be done on the normal gauge with ordinary stock. As to wagons, their carrying capacity was much the same on either gauge. On the Queensland Goot Railways, light wagons with flexible wheel bases were giving every satisfaction. He would have been happy to give details of light railways in the Colonies, had the time of the meeting permitted.

Professor ROBINSON (Past President), having had to advise in the promotion and construction of both light and narrow gauge railways for many years past, appreciated the force of what the author stated, both as to the difficulties that an engineer had to encounter in endeavouring to carry out cheap railways, and also the suggested remedies which were proposed to obviate these difficulties. It was quite clear that there was an ex-

tensive field for the profitable employment of capital in this country, in opening up agricultural and mineral districts, provided this could be done at a much less cost than was possible under the present requirements, both of Parliament and of the Board of Trade. He was not at all confident that the County Councils of the future would prove less expensive tribunals than Parliamentary Committees. Much could be done to cheapen the cost of obtaining Parliamentary powers, and he was disposed to advocate sweeping changes in the present methods, rather than to rely too much upon a totally new and untried system. It was all very well for engineers to assume that the public, through their representatives, the County Councils of the future, would facilitate and encourage the construction of further railways by the imposition of a general tax upon the whole community, but he could see many difficulties in the way which would prevent such anticipations being realised. For instance, there would inevitably be a conflict between urban and rural interests, even in the same district, and there would obviously be the difficulty occasioned by a line of railway affecting more than one district. If the existing Parliamentary machinery could be simplified by referring Bills to one tribunal, being a joint committee of both Houses, by reducing the fees, now unnecessarily high, much would be done to encourage the promotion of light and cheap railways. With reference to the break of gauge, he thought it was undesirable for any fixed rule to be laid down. The ordinary gauge should undoubtedly be adhered to where possible, but in his experience he had to adopt a narrow gauge in two instances, as the physical conditions of the country prevented the ordinary gauge being adopted. It had been stated that level crossings ought to be permitted by the Board of Trade more freely than was the case now, in constructing light and cheap railways in the future. He had grave doubts as to the expediency of relying upon this as a means of cheapening the construction of railways, inasmuch as in the majority of cases where the Board of Trade refused permission they were justified in doing so in the interests of the public safety. The introduction of the bogie engine materially assisted the engineer in laying out cheap railways, and in a discussion on the subject of light railways mention should be made of the data which have been published by Mr. Spooner, Mr. Fairlie, and Mr. Rapier. Some of the first experiments that Mr. Fairlie carried out were made on the Burry Port and Gwendraeth Valley Railway, which he (Professor Robinson) carried out many years ago.

Mr. Perry F. Nursey said Mr. Sellon and another speaker had referred to an improvement made by Mr. Sellon in con-

nection with the working of light railways, but that the meeting had not been enlightened as to what that improvement was. It was really a most ingenious reversible wheel, which could be used on a railway and readily altered to run on a common road.

CORRESPONDENCE.

Mr. R. C. Rapier, Chairman of the Southwold Railway Company, stated that his experience of light railways, in the case of the Southwold Railway Company, had not been favourable, and for the following reasons:—

1. At first the landowners gave most laudable support and promises, but when it came to dealing they were greedy, and also they put the company to much *unnecessary* expense, and caused great waste of funds.

2. At the outset the general clamour of the people for the railway, and the evidence of vehicles and horses kept for hire, seemed to indicate a prospect of adequate traffic; but when that traffic came to be carried at railway rates, the cash receivable for it was of very different amount.

3. The railway has not been a success for the *shareholders as such*, but it has been a splendid success for the population served, and especially for the trading portion of the community. In several instances a man loses 2*l.* 10*s.* per annum on the paltry 50*l.* which he subscribed to the stock of the company, but he clears 200 per cent. per annum by his reduced carriage rate for his goods.

4. In no case should a light railway be made unless the landowners will give their land at *agricultural price* and take it in *shares*, nor unless the ordinary stock is *all subscribed* in the *locality*. *Then* such a railway will pay by its *advantages to the district*, even if it earn no dividend.

5. If a railway be made on the above conditions, there are some advantages in break of gauge, viz.:—

(*a*) The Railway Clearing-house, in the division of traffic earnings, allows rather more than the cost of transshipment to the narrow gauge company, and that makes a small profit.

(*b*) The working expenses are certainly less.

(*c*) The rolling stock of the small company does not get scattered all over the kingdom.

(*d*) The heavy engines of the main line cannot trespass on the light railway.

6. At the same time there is no miracle about narrow gauge, and if, on balance of all considerations, it be decided on, there is certainly no virtue in extreme narrowness. A gauge of

3 feet 6 inches gives all the advantages of enabling the stock to be built as light as possible, and nothing is to be gained by any narrower gauge, unless there be some special circumstances which dictate the gauge.

7. As a general principle no railway will pay, however cheaply constructed and worked, unless there be something heavy to carry and plenty of it; large villages and small towns, even with seaside attractions, will not yield traffic to do much more than pay the most moderate working expenses.

Frequent stations and a man at each station answer better than longer intervals or halts unattended.

The working expenses of the Southwold Railway, of only 9 miles, are about 4*l.* 5*s.* per mile per week. The gauge is 3 feet.

Mr. J. W. Wilson, Jun., could not altogether agree with the suggestion that it would be better to forget all that had occured in previous years in reference to such questions as break of gauge. He was decidedly an advocate for uniformity of gauge under all ordinary circumstances, but he could not avoid coming to the conclusion that in special cases a narrower gauge might be preferable. It might perhaps be difficult, in laying down a narrow gauge light line, to definitely foresee whether it would or would not at some future time become part of a larger system; but, without taking into consideration cases like the Isle of Man, Jersey, &c., where such could not occur, he could not but feel that there was much weight in the contention of Mr. R. C. Rapier, that too much importance might be attached to the consideration of the *future* of a light railway. He would not for a moment ignore the important bearing that future increased requirements might have upon a newly-projected line, but looking at the fact that, as the author had shown in his paper, the success or non-success of a line depended chiefly upon its commercial prosperity or otherwise, it seemed plainly injudicious to overweight such an undertaking at the outset with so great an outlay of capital that it could not hope to pay its own way even, for a long period. Such a mode of proceeding was, however, within his own experience, not uncommon; and he thought in this way much discouragement was cast upon those who sought to promote these undertakings. It was surely wiser to start, even under disadvantageous circumstances, than not to start at all. In the one case there was the probability of the disadvantages being surmounted or discarded in time, but the other alternative meant stagnation. Mention had been made of the loss consequent upon transshipment of coals. In the case of this and other materials, it did not appear that the Clearing-house allowance would always be sufficient to cover the cost of

this deterioration as well as the necessary labour. Moreover, if, as a previous speaker had argued, the farmer was no worse off if he could place his produce on the truck in the field and take it direct to the junction, there to transship it, than if he carted it to the junction and there shifted it into the main line trucks; would not he be better off still in the case of the light line being of full gauge, when he would be saved all shifting. The argument appeared rather to favour the uniformity of gauge than the contrary. There would always be a possible source of danger in the light line forming a direct junction with the main line, from the fact that it would be difficult to ensure the absolute freedom of the former from the heavy rolling stock and especially locomotives of the latter. Doubtless a guarantee would be given to this effect; but how could this be expected to form a permanently insuperable impediment to the running of a heavy locomotive on to the light permanent way of the feeder line? The same difficulty also held good, in a less degree, to the carriages and trucks. For example—a bogie truck, such as that mentioned by the author in his paper, which weighed nearly 10 tons, with a maximum load of 40 tons, would produce considerably more than the limit of 6 to 8 tons on each pair of wheels; however suitable it might be to minimise the resistance due to the sharper curves of the branch line. He had hoped to have heard more during the evening's discussion as to the use of light railways in the form of steam tramways along existing roads. In view of the rapid increase in the carrying capabilities of such lines, as shown by recent statistics, he felt that this matter was coming to the front; and he trusted, with the author, that better opportunities of fair play would ere long be open to the profession and public in this direction.

Mr. Lawford (in reply) said he had listened attentively to the remarks that had fallen from the various speakers, and thought that, as far as he could judge, he should agree with nearly everything that had been brought forward, with perhaps, the single exception, that had been urged in favour of break of gauge; if it was a question of money, and a railway or none at all, by all means make a narrow gauge line. At the same time it must not be forgotten that break of gauge involves a separate rolling stock —whereas by adopting the gauge of the district the same rolling stock serves for the parent line as well as for the light railway. With regard to what fell from Mr. Grover, he could not agree with him that a light railway must necessarily be either a cheap or a bad railway. In other respects he concurred heartily in what he (Mr. Grover) had stated. In conclusion, he begged to thank the meeting for the kind and attentive manner in which they had listened to the reading of the paper.

November 5th, 1888.

ARTHUR T. WALMISLEY, President, in the Chair.

THE PRACTICE OF FOUNDRY WORK.

By H. Ross Hooper, M.A., Stud. Inst. C.E.

In considering the subject of foundry work it may be advisable, before referring to any actual examples, or examining the many details connected with it, to briefly consider the nature of the material used, its properties and characteristics. Castings may be defined as being the product of remelting the foundry pig iron of commerce, and running it into moulds of almost any shape or size; there are however vast differences in the qualities produced by different mixtures. The resulting product may be hard or soft—strong or weak—brittle or tough—rough or smooth, as the case may be, and none of these qualities are in themselves good or bad. All or any of them are good, if applied to the proper purpose, and there is no single iron or mixture of irons generally suitable for all purposes; it is therefore in the proper application of different varieties of iron that the art or science of the iron-founder consists, and this knowledge can only be obtained by long practical experience, or by a sound study of the laws of chemistry and metallurgy.

The several varieties of cast iron, made from different qualities of pig, are classified by engineers generally according to the proportion of carbon contained, although other elements may, and do often, contribute to modifying in a striking degree the properties of this metal. These alloys include aluminum, silicon, phosphorus, and sulphur, of which the first mentioned is remarkable in that its effects on cast iron appear to be entirely of a beneficial character. According to the experiments of Mr. W. Keep, an American engineer, it causes the carbon to separate from the iron at the moment of cooling, so that, when the metal comes in contact with the surface of the mould, a layer of graphite is deposited on its skin, thus forming a perfect plumbago facing to the sand. It increases its transverse strength, and enables it the better to withstand shocks and blows without injury to itself. It also diminishes the shrinkage, renders the grain more uniform, prevents chilling, and converts the hardest white iron into grey. Its effects, however, appear to

vary according to the different natures of pig; with some irons a very minute addition will give the most satisfactory results, whereas with other qualities it is quite inert. General observation seems to lead to the conclusion, that the more inferior the quality of the iron the more beneficial is the influence exerted by the alloy in question, and vice versâ. The quantities which require to be used with white iron vary from 0·5 to 1·0 per cent., and with grey iron from 2·0 to 4·0 per cent.; but at its present price of twelve shillings and sixpence per pound, this means an increase on the cost of castings of about £10 per ton in the former and from £20 to £40 per ton, in the latter case. This of course renders its use for practical purposes impossible, although doubtless, as the manufacture of aluminum is now only in its infancy, its cost of production will ultimately be very materially reduced, and fresh experiments will prove its more general scientific value. Silicon, the metallic base of ordinary sandstone or white sand, acts upon iron in much the same way as aluminum, only in a lesser degree, its effect is to soften the iron, improve the grain, and to convert white iron into grey, thus enabling sound castings to be made from "scrap" and inferior metal. It is always present, in proportions varying from 0·2 per cent. up to 30·0 per cent. in ferro-silicon, and requires a very high temperature for its reduction. It serves to increase the strength of iron, provided that its amount does not exceed about 2·0 per cent.

Phosphorus, like manganese, gives fluidity to the iron without reducing its melting point; it hardens and tends to make the iron white, and should not be present in a larger amount than 0·2 per cent. Sulphur has always a damaging effect, it will dissolve in iron to an unlimited extent; it gives a dull pale grain, and makes the iron spongy and brittle. There are, however, very few ores or fuels which do not contain sulphur, and the only way to prevent it from combining with the iron is to use a good basic flux.

The differences in the many varieties of pig iron depend upon the quantity of fuel used in the reduction of the ore, the heat at which that reduction is effected, and other influences.

Before proceeding to consider these varieties, it is necessary to call attention to the fact, that there are two distinct forms in which carbon exists in cast iron, viz:—

1. "In the state of mechanical mixture," where the interspersed carbon is visible to the eye in the shape of small black specks, giving the metal a dark grey appearance.

2. "In the state of chemical combination," where the carbon is invisible, and can only be detected by analysis.

Cast iron contains from 2·0 to 6·0 per cent. of carbon, and

its properties do not so much depend upon the amount of carbon present as upon the conditions in which that carbon exists. The varieties containing a large proportion of free carbon are of a dark-grey colour, of a soft nature, and run freely into moulds. When the carbon is all, or nearly all, in chemical combination with the iron, there are no black specks, the metal is white, very hard and brittle, and forms when fused a somewhat pasty mass which will not freely fill a mould. The former of these classes merges gradually into the latter, and between them there are numerous gradations.

All cast-irons are consequently not suitable for foundry purposes, the requisite conditions being a sufficient fluidity to allow of the metal filling every part of the mould, combined with a small degree of shrinkage and a strength adequate to the purposes to which it is to be applied. This quality is for general requirements judged by its colour and texture of grain, and should show an even and crystalline surface on fracture, with a fairly high metallic lustre.

Cast iron may be generally classified under two heads, viz. grey iron and white iron. These two varieties may always be distinguished from each other by treating the surface of fracture with nitric acid; on grey iron a black stain will be produced, and on white iron a brown stain. The grey iron, however, is almost exclusively used in the foundry, owing to the white being of too hard and brittle a nature for practical purposes, and is only employed for such purposes as ballast, window sash weights, &c.

The grey iron may be subdivided under three heads, of which No. 1 is of a dark grey colour, caused by the amount of contained graphite carbon; the crystals are large and sparkling, assuming the appearance of freshly-cut lead. It will easily melt into a very fluid state, and is therefore well adapted to the sharp delicate castings required for ornamental purposes. No. 2 contains less graphite carbon, and is therefore of a lighter colour, closer in grain, and more difficult to melt; it is considerably harder, and therefore better suited for machinery, girders, and similar purposes, where strength and durability are essential. No. 3 is of a still lighter colour, containing less carbon than No. 2; it is harder and more nearly approaching the characteristics of white iron, and is only employed in heavy castings.

White cast iron sometimes contains as much carbon as the grey varieties, but of this nearly all is in a state of chemical combination, whereas in the grey iron a very large proportion of it is free, only about 1·0 per cent. being in chemical combination.

Mottled cast-iron contains both the grey and the white varieties, and can easily be distinguished, the fractured surface being white with grey specks, or grey with white spots or patches.

In the manufacture of cast iron, from 3 to 5 cwt. of the above described qualities of pig are mixed with 1 ton of suitable "scrap" or old broken castings, to melt down which about $2\frac{3}{4}$ cwt. of coke will be required, depending however, to a very considerable extent upon the form of furnace used.

A careful consideration should be observed in the designing of cast-iron work with reference to the crystallisation which takes place on the cooling of the metal. Iron which has been poured into a mould, on changing from a liquid into a solid state, becomes a mass of crystals more or less irregular, but tending to the form of an octohedron. When some portion of a cast-iron structure has failed, it may be not unfrequently noticed that the laws affecting crystallisation have not been duly taken into account. Fig. 1 illustrates the instance of a hydraulic press cylinder which failed by bursting out the sides, and was due to the lines of the crystals, when forming, being developed in a direction at right angles to the surfaces forming the corner, so that between the two sets of crystals there was a diagonal line of weakness. To obviate this a second cylinder was designed, as shown in Fig. 2, whereby the axes of the crystals were directed towards the centre, and thus, having only a gradual change in their direction, planes of weakness were avoided.

Sharps, corners, or angles, are therefore a source of weakness, and should be rounded off. There should be no great or abrupt differences in the bulk of the adjacent parts of the same casting, otherwise as the small or thin portions will cool and contract first, they will resist the contraction of the larger parts, while the larger, contracting last, will compress those portions already cool; and the casting is consequently subjected to stress before it is called upon to bear any extraneous load. In some cases this strain is so great as to cause the casting to split and break up spontaneously.

There are three principal operations involved in founding, viz.:—

1. Moulding; or the production of a hollow mould to receive the metal.
2. Melting; or running down the metal.
3. Pouring; or filling the mould with the liquid meal.

In order to mould a quantity of melted metal into any required form, two things are necessary, viz. a model or pattern of the article to be produced, and a substance of sufficient suscepti-

bility and adhesiveness to receive accurately and to retain the impressions of the pattern made upon it, and at the same time to resist the impact of the liquid metal when run into the space.

Pattern-making is a trade in itself, and quite distinct from other branches of wood-work, such as joinery and carpentry. The pattern-maker requires to be thoroughly conversant with the principles of moulding, otherwise his pattern will cause trouble to the moulder.

Patterns are usually made of wood, though sometimes of metal, especially where a very large number are required, while cements, plaster of Paris, wax, terra-cotta, and papier-maché are occasionally employed. The most suitable wood is that which possesses a smooth even grain, and as few knots as possible; it must be thoroughly seasoned, easy to work, and at the same time cheap, for which reason white or yellow pine is most frequently employed; though patterns of a delicate nature, or carved work, should be made from mahogany or plane-tree. There are many other woods equally suitable, a detailed account of which may be found in works relating to this subject. It requires considerable forethought on the part of the pattern-maker to so construct his pattern that it may be easily withdrawn from the sand, it being necessary in many cases to make it in detachable pieces, in order that it may be taken out in parts; also certain portions, such as the ribs of bearing blocks, &c., are made with a slight taper, usually $\frac{1}{8}$ inch, to the foot, for facilitating the "drawing" of the pattern.

When holes or cavities are required to be made in castings, as for example, in pipes, bolt-holes in bed-plates, or the hollowing out in large castings for the purpose of reducing the weight and thus saving cost, projecting pieces called "prints" are fitted to the pattern, thereby making recesses in the moulds into which the cores may be fitted. As a precaution against defects in the wood, and as a preservative, the patterns are usually coated with a varnish or oil paint. Weak shellac varnish, composed of two parts of shellac to twenty parts of methylated spirit, also forms a very good protection. As molten iron cools down, it contracts, as a rule $\frac{1}{96}$ in all its dimensions, to allow for which, the patterns require to be made proportionately larger; but in small castings of six inches or less this is compensated for by the shake in the sand, given by the moulder to the pattern in order to extract it from the mould.

Moulding may be divided into two branches:—

(i.) Moulding in green and dry sand.

(ii.) Moulding in loam.

In the former case, patterns of the work required are universally employed in forming the mould; in the latter case, patterns are dispensed with, the objects being heavy castings of a regular form, usually of a cylindrical type, such as gas retorts, rollers, &c., and this method is generally restricted to forms which cannot be conveniently moulded in any other way. Dry sand moulding is chiefly employed for the making of knuckle-bearers, bending blocks, and long cylindrical bodies; it is firmer and better adapted to purposes of this kind than green sand, and is composed of equal portions of new sand and ground loam mixed with road scrapings and coal dust; it is called dry sand in contradistinction to green sand because, after being moulded, it must be dried by heat to fit it for the intended purpose; whereas the latter being a weaker sand is used in a damp condition, which however must not be excessive, or, when the metal is poured in, the generated steam will cause "blow holes," cavities, and "scabs" in the casting, or the metal may be repelled altogether and be explosively shot out of the mould; again, if the sand be deficient in moisture, the iron is apt to penetrate its pores on the under surface, and by detaching particles of sand, produce an unsound casting.

The requisites of a good foundry sand are a fine and uniform grain and a certain amount of cohesiveness without being sticky, freedom from oxides, and infusible at the temperature of the metal poured. Such sands are easily procured in most parts of the United Kingdom, the best being those obtained from the alluvia of the Thames and other large rivers.

When molten metal is poured against sand, that part which is contiguous to the metal becomes burnt, and the casting is roughened in consequence; hence all facing sands are mixed with coal dust, which prevents the surface of the sand being fused by the metal, as the coal dust, in becoming oxidised, interposes a protecting film of gas between the metal and the sand.

In the process of sand moulding, "boxes" or "flasks" made of iron are always employed for the purpose of containing the sand in which the pattern is moulded. These boxes are, for convenience, of various shapes and sizes; should there be a great demand for castings of one form, boxes are made expressly for them, thereby saving labour, as the ramming-up of useless corners is avoided. These boxes (or more correctly speaking rectangular frames) varying from four to seven inches deep, are made in similar parts so as to fit one over the other, being kept in position by pins attached to the sides of the upper box, which fit into corresponding holes or lugs in the lower box. The larger boxes have transverse ribs about half the depth of

the box, joining the opposite sides at equal distances of four or five inches apart, their object being to act as holding surfaces for the sand, which is formed into a close and adhesive mass by ramming. Handles are cast on the boxes to enable them to be lifted and moved about.

The details of the process of moulding a simple type of bed-plate for a small girder (Fig. 3) is as follows: Two suitable boxes, somewhat larger than the pattern, are first procured. The pattern A (Fig. 4) is laid down on a flat board B of sufficient size to support it in all parts. A layer of fine sand, called "facing sand" composed of new sand and finely-ground coal dust is sifted over it to a uniform depth of about half an inch. Then upon the board the lower box C, having strengthening ribs D, is placed in its proper position with respect to the pattern. An addition of common sand, such as that composing the foundry floor, is passed through a riddle, and the whole carefully rammed down. The sand being properly set, and squared with box C, the whole is turned over and well bedded in the ground, care being taken to avoid sudden shocks, which would tend to loosen the sand. The board B is then lifted off, and the upper surfaces in the box C are cleaned and smoothed with a trowel, so that the sand is flush with the pattern and meets the edges of the box. This forms the parting or plane of separation in the two boxes, which is dusted over with "parting sand" composed of finely-ground cinders, or the burnt sand off castings, its object being to prevent the sand of either boxes from sticking together. The top box E (Fig. 5) is then laid on, being guided by the pins fitting into the lugs of the lower box C. Gates or passages for the iron to be poured into the mould have now to be considered. In this case two will be required, one F (Fig. 5) for the in-pouring of the metal, the other G, termed a flow gate, is plugged with a ball of clay or loam K, to "keep down the air" in the mould while the metal is being run in, and is withdrawn when the mould is full, allowing the metal to run out, carrying with it any dirt that there may have been inside. The plug must not however be withdrawn too soon, as by the too free egress given to the air, the top of the mould is apt to be disturbed, owing to the air striking "downwards" instead of "up" through the top box, and so tend to pull down the top of the mould. To provide for these gates, two taper pins of wood called "gits" are stuck into the sand of the lower box, at a short distance from the pattern, and projecting up between the ribs of the upper box. Sand is then rammed in until the box is filled up flush with its top. The taper pins are now withdrawn, and the holes formed by them widened out to receive the metal more easily.

The upper box is then lifted off, and should show on the underside a perfectly smooth surface. The edges of the moulding of the box C in contact with the pattern are next wetted with a brush to make the sand at the corners firmer and to prevent it from crumbling on withdrawing the pattern. To withdraw a pattern is in many cases a very delicate operation, as it fits closely in its bed, and requires to be loosened before it is drawn; which is effected by taking hold of the pattern and tapping it gently laterally and downwards. After the pattern has been removed the mould is mended up and trimmed where necessary, and *blacking* applied on the exposed parts, with a soft flat brush, to resist the penetrating action of the metal on the sand. Channels are then scooped out on the surface of the lower box, joining the gate holes with the moulding, a small fillet being made on the mould to prevent the runners breaking into the casting on being knocked off. As holes in the bed plate will be required for the holding bolts to pass through, "prints" H H (Fig. 4), corresponding in size, are fastened on to the pattern, which when withdrawn will leave holes in the sand into which the cores may be fitted. Having finished the mould and got it in order for the reception of the metal, the top box is replaced and clamped down J J (Fig. 5), to prevent the metal from lifting it up and running out at the place of separation. Figure 5 shows the mould finished and ready for the pouring in of the metal. It is necessary to pierce the sand with holes by means of a thin wire (which is done before the pattern is withdrawn) to allow for the escape of the air and gases evolved when the metal is poured in, and is termed "venting"; for if these gases are permitted to force their way through the metal they will cause it to be unsound and full of flaws and small cavities. Although the foregoing is a description of one of the simplest types of moulding, all the particulars and details apply equally to every variety of sand mouldings.

When a casting requires to be hollow, a pattern of its inner surface, called a "core," is formed in sand or loam, so that the metal may flow around it these cores being fitted into the recesses in the mould caused by the corresponding prints in the pattern. Cores, naturally, are of every variety in shape and size; they may be long and thin, winding or otherwise intricate, and in that they are destined to be surrounded with metal it is necessary to pay considerable attention to their manufacture. Their qualities should be firmness of substance and openness of pores, and they are usually made of rock sand and sea sand, the former having a percentage of clay, which gives the necessary cohesiveness, while the sand being loose and open renders it porous. Long cores require to be stiffened with wires or thin

rods, bent where necessary to their form; they must also be pierced longitudinally, to allow for the escape of the air and gases, a matter of great importance, as castings are not unfrequently rendered useless owing to want of care on this point, viz. the proper ventilation of the cores. When the cores are large and of sufficient thickness, coke ashes are employed for this purposes; when winding and thin, pieces of string are laid in the sand or loam, alongside of the stiffening irons, which can be afterwards drawn out on being dried. Cores should never be put into a green sand mould until just before casting, as they are liable to absorb the moisture, and so tend to form blow-holes in the casting. When the bearings at the extremities of the cores are insufficient to steady them, as in the case of a curved pipe, they are sustained by means of flat-headed nails called "chaplets" or "steeples" set into the sand, and projecting above it to the extent of the thickness of the metal. A coating of blacking is given to cores, which is the more necessary as the cavities filled by them are usually difficult of access, and an easy scaling off of the sand from the iron is desirable.

Cores are not always absolutely necessary, as they are frequently employed merely to save expense in the making of the pattern, and in moulding to render a successful cast more certain.

For the making of small cores a core-box (Fig. 6) is used, which simply consists of two blocks of wood fitting closely together, having a cavity inside corresponding to the shape of the core; sand is rammed down into this recess, a vent wire passed through, the blocks taken apart, and the core lifted out and dried.

Figure 7 shows the section of a core for a large pipe or column, consisting of a thick cast-iron tube A, pierced with holes B, B, B, B, around which is wound a twisted hay rope C, for the purpose of venting the core, over which is plastered a thick layer of loam D, pressed hard down with a wooden block, then dried, and finally coated with strong blacking. The barrel is mounted between two trestles and turned with a handle, thus giving it the required cylindrical form, as shown in Figure 8. The object of the hay rope is not only to act as a conducting medium for the air through the loam, but also to bind it to the barrel; and again, when molten metal is poured in, it burns the hay rope, thereby releasing the barrel and enabling it to be withdrawn as soon as the metal has set, to allow for the free contraction on cooling.

Loam moulding is the most ancient branch of moulding, its peculiar feature being to construct a mould without the expense of a pattern for the purpose. The economic employment of loam as a substitute for patterns and sand is restricted in

general to the manufacture of the more regularly-shaped work of the foundry. Loam moulding as a rule, except in the cases of simple forms and heavy castings, is more expensive than any other kind of moulding. Every piece of loam moulding is a regularly constructed edifice, composed of bricks bedded in loam, with which they are completely coated and worked to form a smooth external appearance. The most important part of this branch of moulding is the composition of the loam employed. It demands the strictest attention, and is varied according to the object to be moulded, for loam suitable in one case will not necessarily answer in another. Firmness, porosity, and as little shrinkage as possible on drying, are the indispensable qualities. Firmness, to resist the great pressure to which in large castings the moulds are subjected; porosity, to offer a transit sufficiently free to allow of the escape of the gases evolved by the heat of the metal; slight shrinkage in drying, to obviate cracks and crevices into which the metal will run, causing uneven and rugged surfaces on the casting. To fulfil these conditions loam is composed of clay and clean sharp sand; from the former, owing to its binding nature, it derives its firmness, from the latter an open grain. Cow-hair is also usually added, assisting the tenacity in the first place, and secondly, when the mould is baked the hair becomes scorched out, thereby causing minute perforations. Horse-dung and chopped straw, in the case of cores, are used to render the loam rotten after casting, enabling it to be the more easily broken up. Every loam mould on completion requires to be very thoroughly dried and baked, in order to anticipate as far as possible the work of the molten metal, by expelling the humidity and the gases evolved by the burning of combustible matter. For all circular bodies, such as may be described round one axis, a wooden board is cut on one edge to the exact form of the object. If the body be cored out, a second board is required, cut to the form of the interior of the space. A central spindle is erected, corresponding to the centre of the body to be moulded, to which an arm is screwed provided with slotted holes, by which the loam board or "strickle" is set and fixed at the proper radial distance from the centre. The whole being in this condition turned round, it is obvious that the figure of the body will be described.

Figures 9, 10, 11, 12, 13, illustrate the method adopted by a well-known London firm, for the making of a large cast-iron drum, five feet in diameter and two feet six inches high, capable of containing two hundred feet of wire rope, (one inch diameter) employed in the erection of the Sukkur Bridge in India.

In describing the process of the construction of the mould, it may be advisable to first consider the construction of the core.

In this instance, owing to the core not being bedded in the sand, as is the case with columns and cylinders when cast vertically, it will be necessary to form a seating or dummy upon which to build the core.

A circular plate A (Fig. 9), with a central hole for the spindle, and six holes to allow the air pipes for venting the core to pass through, is first procured. A loam board C (Fig. 10) is fastened to an arm screwed to the spindle at the proper radial distance; sufficient loam, made up with bricks, is then laid on, and an exact counterpart of the underside of the core is "struck up," which when dried forms the seating upon which to build the core.

Parting sand is freely strewn over the dummy or seating, and a bedding of loam sufficient to allow the bottom plate D (Fig. 12) being placed thereon, having "dabbers" or prongs to hold the loam together. This plate, as shown in Fig. 11, has six holes into which the ventilating pipes are screwed, and a similar number of hooks to which the long bolts E E (Fig. 12) are attached, joining the top and bottom plates, and thus rigidly keeping the core together. The holes near the centre of the plate are for the three gates which pass through the middle of the core, these of course being afterwards cut out. On the bottom plate the sides of the core composed of bricks and loam are built up, having a stiffening ring I in the middle. The top plate similar in design to the bottom one (Fig. 11) is placed on, the hooked bolts fastened up, and another layer of loam added, the whole being worked into the required form by the loam board H (Fig. 12). J J shows a hay rope running round the rim of the core for the purpose of venting the loam, it being rather thick at that place. The gates L are preserved by means of thin wooden rollers which on the removal of the spindle, and loam board can be drawn out. After the core has been thoroughly dried in the stove, six tapered recesses are cut in the top of the core, K K (Fig. 12) to allow coke ashes and cinders M M to be rammed in, thus forming a perfectly solid yet porous hearting. These holes are then carefully closed with blocks of loam cut to the shape of the recesses. The core is then given a strong coating of blacking, and is ready for use.

The outside copings have now to be considered, and precisely the same process of "striking up" their outside surfaces is observed. A thick iron circular plate, similar to that shown in Fig. 9, but freely pierced with air-holes, is laid down, and the bottom of the mould is struck up, in the manner shown in Fig. 10, holes being cut out to allow for the ventilating pipes from the interior of the core to pass through. The top of the mould is treated in exactly the same way, with the exception of the

three gates or passages being made therein for pouring in the metal. To form the ring, a seating requires to be made corresponding to the form of the outer edge of the bottom part of the mould. This ring is built up of bricks and loam, having an iron ring on the top and bottom, to add to its support and enable it to be lifted about. When these parts have been constructed and thoroughly dried, they are given a strong coating of blacking and then put together, an operation which requires considerable care.

The bottom of the mould A A (Fig. 13) is laid down, and six cores B B placed thereon at equal distances apart, through which the ventilating pipes pass. These cores are heart-shaped and of the exact thickness of the metal; they are made in special core boxes, and as they have to support the central core, require to be very strong, and therefore contain an iron plate only slightly smaller than the cores themselves, to allow for a coating of loam. A small round core C is fitted in the centre of the boss to make provision for the axle. The large core E E is then placed on, followed by the outer ring D D; on the former there are laid six more cores B^1 B^1, corresponding in shape and size to those used at the bottom, and likewise a similar core C^1. There remains then only the top F F to be placed on; this is firmly bolted to the bottom plate, thus rendering the entire mould one compact and rigid body, which is sunk into a pit dug out of the foundry floor, and the sides tightly rammed up with sand, to prevent the mould from bursting out under the pressure of the metal. Care must be taken to form channels in the pit to carry off the gases issuing from the six ventilating holes, which may be done by laying down a ring of coke ashes, connecting all the pipes, and connected with two or three large flues leading up to the top of the foundry floor. A large basin of loam or sand is made up in a box, and placed on the top of the mould, forming a convenient hollow into which to pour the metal, there being three ducts leading to the gates running through the core.

Of course it must be understood that there are many ways of constructing a mould for such a drum, but the method employed proved very satisfactory. The expense connected with the making of a mould such as this is very considerable, as its construction occupies the time of three men for one week, their wages being 2*l.* per week each, and a labourer at 1*l.* 1*s.* per week is required to prepare the loam and work the cranes. The cost of the iron and fuel and general foundry expenses may be assumed as 5*l.*, or a total sum of 12*l.* loss should the casting turn out what is usually termed a "waster."

In cases where a very hard surface is required on certain parts of a casting, as for example in the treads of railway wheels, or the

extremities of projectiles, the practice termed "chill casting" is employed; this is simply effected by using iron instead of sand, for the matrix of such portions of the casting as require to be chilled, as the metal when brought in contact with these iron parts cools so rapidly as to be converted into the hardest white iron.

Fig. 14 shows the section of a chilled mould for a railway wheel. It consists of three boxes. The lower one is of a common form, to hold the sand and give support to the centre core and middle box, the upper box is precisely similar whereas the middle box is made of strong grey or mottled iron, bored out in a lathe the reverse of the exact form of the perimeter of the wheel. All the three boxes are connected in the usual manner, with pins, lugs, and clamps. The chief difficulty with these wheels is to make the strains due to contraction uniform in amount, and so prevent fracture. Wheels with spokes are very liable to this evil, and require to be cast with their "hubs" A A (Fig. 14) split into two or more sections, which are afterwards bound together with wrought iron bands shrunk on. As soon as the metal is set after casting, it is advisable to dig out the sand round the central portion, in order that the hub may cool as rapidly as the rest of the wheel.

What is known as malleable cast-iron is largely used in nearly every trade, for the manufacture of those articles which require a tough and fibrous nature, but would be too expensive if forged. The following is a brief outline of the process. White or mottled pig-iron is melted in clay crucibles and run into the ordinary green or dry sand moulds; the castings having been thoroughly cleaned from sand are placed in cast-iron "saggers" or "annealing pots" with alternate layers of fresh clean sand and powdered red hæmatite ore, or better still the fine iron scales from the rolling mills. These saggers are then placed in a furnace constructed for the purpose, where they are exposed to a gradual heat, rising to a full cherry red, when the articles are allowed to cool slowly, being kept in the pots till quite cold. When removed they are cleaned with hæmatite powder and the process is complete. The time during which they should be exposed to the heat of the furnace depends upon the size of the articles and the depth to which they are required to be made malleable. Cast iron thus treated is capable of being welded, but will not stand tempering; it may even be bent double when cold, but will fail on being bent back again.

A system of moulding known as "Jobson's Blocks," especially adapted for large thin castings, such as fire-places, copings, &c., designed by a Mr. Jobson, is a very simple process. Figures 15, 16, 17, 18 will of themselves almost explain the *modus*

operandi. The pattern is bedded in the sand in the bottom box A (Fig. 15) to a convenient joint, as in the ordinary process of moulding, and the parting surface accurately formed; the top box B is then placed on and filled with plaster of Paris, to which the pattern itself adheres. The plaster being set, the boxes are turned over and the sand carefully taken out of the bottom box; a similar process is then repeated with it as in Fig. 16, using clay wash to prevent the two plasters from uniting, thus forming a corresponding plaster mould A^1 (Fig. 16). These two moulds A^1 and B are termed "waste blocks," and are not used for producing the moulds for casting. Reverse moulds C and D (Figs. 17, 18), are made in plaster from the waste blocks, from which the final sand moulds are made, by using them as ramming blocks. This is done by placing a box upon each of the blocks C and D, and ramming down sand upon them, thus an impression will be made in the sand precisely similar, as though an ordinary pattern had been used. Runners, gates, and risers are made previously in the original sand moulds, and are consequently formed in the succeeding ramming boxes. Any number of moulds can be made from the original blocks C and D by the simple process of ramming, no handling of the pattern or turning over of boxes being required, as both the top and bottom boxes can be rammed independently and at the same time if desired. Ordinary labourers are sufficient to make the sand moulds from these blocks, which tends to greatly lessen the cost of what in the usual process of using a pattern would be an expensive piece of work.

Various methods are adopted for casting, according to the form or requirements of the casting. Large columns and cylinders are generally specified to be cast vertically, that is, when the mould is standing on end; for by this means the metal is more likely to be of uniform density and thickness all round, and there is less chance of the core being shifted out of its place by the metal on filling the mould. As large castings are liable to be spongy and unsound in the upper part of the mould when filled from above, an extra length, called a "dead-head," is given at the top of the mould, wherein all the sullage and dirt can rise, which is afterwards cut off. The strength of a casting is increased if it be run with a "head" or superincumbent column of metal which by its weight compresses the metal below, making it more compact and free from air bubbles, &c., for which reason a vertical side runner is sometimes employed whereby the metal enters the mould from below. Sir Joseph Whitworth, in the case of steel, adopted with great success a method of applying hydraulic pressure to the mould,

until the metal had solidified, thereby rendering the casting sounder and the grain closer. When a perfectly smooth working surface on the top and bottom of a casting is required, as in rockers for large spans where a saddle bears on the top and the bottom slides on rollers, it is best to cast them on end, that is, with the two working surfaces vertical, a small "dead-head" being made at the top of each of these surfaces. Testing bars are usually cast in an inclined position as shown in Fig. 19, the metal being poured in through a long runner and flowing up the mould into the riser at the top. This will give a good sound casting, as the weight of the metal in the runner will compress the crystals into a closer grain. Melted iron when cooling, naturally cools the fastest at the external surfaces of the mould, thereby drawing the molten metal from the hottest or central portion to supply the shrinkage due to the contraction of the cooler parts, and if this central or latest cooling portion of the iron be not reached with a feeding rod, and hot iron added to compensate for the shrinkage, it will be found to be honeycombed, or even a cavity to be formed of three or four inches in diameter. A gate or feeder is therefore made through the top box leading direct to the thickest part of the casting (in some cases several of these may be required) on which is placed a cup, wherein hot metal can be poured to supply the shrinkage, being worked down to the centre by an up-and-down movement given to the feeding rod. It may not be generally known that all castings of columns, screw-piles, &c., if cast horizontally, and not "fed" in the manner described will be found cracked. This crack will occur, in the case of columns, between that part marked A^1 A and B^1 B (Fig. 20) while with screw-piles it will be found that the screw has withdrawn from the main portion of the pile. To prevent these cracks, which are not visible on the exterior surfaces, it is necessary to form a feeding head which will directly supply metal to make up for this shrinkage. Moulders will sometimes, to save themselves trouble, make up a flow gate instead, but this may easily be detected as it is smaller than a feeder, the latter being not less than two and a quarter inches in diameter. It is impossible to produce sound castings without careful attention being paid to feeding, and it is an indisputable law that without feeding cracks and cavities must occur, owing to the shrinkage of the metal on cooling; notwithstanding this fact, there are, to the author's knowledge, foundries where the use of a feeding rod is unknown.

As regards furnaces, the type usually employed for iron is the cupola; it has the advantages of doing its work more cheaply than any other kind, and of being a convenient appa-

ratus, capable of melting from half a hundredweight, up to 5 or 6 tons in a short time, and with a comparatively small expenditure of fuel. Although these furnaces vary in many points, such as the outline of the interior shell, some having a convex curve just above the tuyere holes, with the view of reducing the amount of fuel; others, again, having a false bottom; still the general features of the furnace remain the same. Figure 21 illustrates the ordinary cupola, cylindrical in form, built of fire-bricks, laid as headers with a casing of wrought-iron plates or cast-iron rings, the former, however, are the more durable, as they better withstand the effects of alternate expansion and contraction. The height varies according to the diameter, it being usually from four to five times the latter.

Fig. 21 shows the half section and half elevation of a cupola; A is the casing of thick wrought-iron plate, strongly riveted together; B is an opening about two-thirds of the way up, for charging the cupola; C C are tuyere or blowholes, through which the blast supplied from a fan or blowing engine is forced into the furnace; D is the tap-hole, towards which the bottom of the cupola should have a gentle slope; E is an iron base plate; F the foundation. A furnace of this description, 10 feet high (i. e. up to the charging hole) and 3 feet 6 inches in diameter, is capable of melting at a single charge about 5 tons. For small cupolas only one tuyere is used, but the number requires to be increased in proportion to the diameter, so as to generate a uniform heat. Those cupolas which are constructed with a false bottom or hinged trap door, to allow the contents to be dropped into a pit underneath after casting, are more easily emptied than by "raking out," but, though time is saved in this point, a more than corresponding amount is lost in relining the bottom when again used. Cupolas of this description were erected in Woolwich Arsenal, but were soon given up and the old type adopted.

A raised platform, as shown in Fig. 21, is necessary, from which to charge the cupola; it must also be large enough to allow for the stacking of coke, limestone, pig, and scrap iron. Coke should always be of good quality, free from sulphur and ash, and possessing hardness and compactness, for no saving is effected in the ultimate cost of cast iron by purchasing inferior material, which will give less heat and is more likely to damage the iron.

When the cupola is to be charged, the apron H (Fig. 21) is removed. Firewood and coke are ignited, and when well alight, a quantity of loamy sand is rammed into the breast opening, and the apron brought forcibly down through the

sand, and is kept in position by an iron cross-bar, fitting into two lugs attached to the casing; the tap-hole being preserved by an iron bar placed through the sand. Alternate charges of coke and iron are then thrown in through the charging hole, and, when the furnace is thoroughly heated, the blast is put on. This will drive a flame through the tap-hole, drying and glazing the fresh sand, so as to resist the friction of the tapping-bar. Lumps of limestone, in quantities of from 2·0 to 5·0 per cent., are put in with the iron and coke, to act as a flux and combine with any earthy matter present, forming a glassy "slag," and preventing it from adhering to the sides of the furnace. When more iron than the cupola will hold at a single charge is required for one casting, a portion of it is tapped into a large ladle, a few shovels full of sawdust being thrown over it, which speedily becomes converted into a cake of charcoal, thereby preventing the air from reaching the metal and cooling it; by this means good sized castings may be obtained from a small cupola.

Reverberatory furnaces are now seldom used for cast iron, for they are neither economical in fuel or metal, except where operations are constantly going on from day to day, on a very large scale, and where bituminous coal fuel is cheap. The Phosphor Bronze Company erected one at a considerable cost, but it was only used a few times. They require to be kept in a state of perfect repair, and for ordinary foundry work cannot be recommended.

A drying stove, proportionate to the size of the foundry, is necessary for the drying of the moulds and cores; it is generally built of sound 9-inch brickwork, with iron shelves arranged along the sides, and having large iron-plate doors opening the full width and height of the stove; a good system of ventilation is essential to prevent the air from getting charged with moisture. An open hearth is built either in the centre of the stove or at the side, but the former position is most advantageous, as it distributes the heat more thoroughly.

Large moulds are dried *in situ* by placing over them "kittles," containing a coke fire. A practice adopted in some foundries is that of drying with a current of hot air introduced into the centre of the moulds, and allowing it to escape through the gates used for pouring the metal in, thus doing away with the shifting of heavy weights, which is not only tedious but costly. This current of hot air is conveyed by means of pipes leading to the moulds from a walled pit, closed at the top with a hinged iron plate, containing a grate proportioned to the size of the castings, the current being maintained by a blast of air driven into the base of the pit by a fan; a thorough control is

preserved throughout by a system of dampers, and with proper attention there is no possibility of burning or unequally drying the moulds. The heat, moreover, is better applied, than with the somewhat primitive method of suspended kittles, as the hot air acts equally on every side, and is not obliged to penetrate the whole thickness of a mould before reaching the opposite side.

The metal is carried from the furnaces to the moulds either in small hand-ladles, "shanks," or large ladles. These are simply made of riveted iron boiler plate, lined with fire-clay and a coating of black wash applied; care being taken that the lining be thoroughly dry before use. They are pierced with a few small holes to allow of the escape of gases generated by the heat of the metal. In pouring the metal from the ladles into the moulds, an instrument called a skimmer (a hook-shaped piece of flat iron) is used, as its name implies, to prevent the slag and dirt from running into the mould; it is simply held across the lip of the ladle, thus holding back the scoriæ which float on the top.

Cranes and travellers suitable for lifting heavy weights are usually of two kinds, "overhead" and "swing jib" cranes. Each type possesses its advantages; in the case of the "overhead" cranes, because they occupy no space on the floor of the shop and are especially useful for carrying the large ladles of metal to the moulds. Swing cranes placed at convenient corners are applicable for lifting moulds and heavy castings out of the sand. To have a scarcity of cranes in a foundry is about the most expensive form of economy that can be adopted, owing to the loss of the moulders' time in waiting until they are at liberty.

The operation of casting is usually performed in the afternoon, so that the castings may have plenty of time to cool during the night. On the following morning they are removed to the trimming or "fettling" shop, the runners and risers being previously knocked off; here the usual excrescences, fins, and all ragged edges are chipped off, and finally scraped with old files and rubbed over with a piece of hard firebrick. Grindstones are useful in doing the work of the chisel and file, but neither are so satisfactory as solid emery wheels, which occupy little space and can be run at a speed that would be dangerous in the case of grindstones, owing to their liability to crack asunder. Of course castings which are too heavy or too unshapely to handle with comparative ease, cannot be trimmed other than with the chisel and file.

In examining castings with a view of ascertaining their quality and soundness, several points should be attended to.

The edges should be struck with a light hammer, and if the blow makes a slight indentation the iron is probably of good quality, provided that it be uniform throughout. But if fragments fly off and no sensible impression be made, the iron is hard and brittle. Air bubbles are a common and dangerous source of weakness, and should be searched for by tapping the surface of a casting all over with a hammer. The metal of every casting should be free from "scabs," bubbles, or flaws of any kind. In foundries of low standing, these defects are often hidden by being filled up with a trashy composition known as "beaumonteque," (composed of putty mixed with parting sand, to resemble the colour of the iron), of which so much was heard in connection with the disastrous failure of the Tay Bridge in 1879. It may generally be detected by the greasy mark which it leaves on the casting. The exterior surfaces should be smooth and clean, the edges sharp and perfect. An uneven or wavy appearance indicates unequal shrinkage, caused by a want of uniformity in the texture of the iron or by unequal cooling. The surface of fracture, examined before it has become rusty, should present a fine-grained appearance of an even bluish-grey colour and a silvery metallic lustre. Cast iron pipes and cylinders should be straight and true in section, square on the ends and in the sockets, and the metal of equal thickness throughout. They may be proved under a hydraulic pressure of from four to five times their working load. The quality of work in this country is dependent to a great extent on the inspectors; it is through them that the work is passed or rejected, and, owing either to a want of knowledge in foundry practice, or a lack of firmness of mind, work is sent out so defective as to be often quite unfitted for the intended purpose, not only causing a waste of time and money, but, what is most important, tending to lower the tone and depreciate the trade in every way: and, *per contra*, the inspector who shows too much zeal by wrangling over little defects which are really of no consequence, is almost as much to blame as the one who fails to show any interest in the work. It is the medium between these two extremes that is required; an inspector should condemn absolutely such work as he considers unfitted for the intended purpose, but he should also be ready to show his appreciation for the first class work which is turned out by many of our English manufacturers.

For small girders and other castings intended to carry weight, it is usual to test a certain proportion of the number supplied, by loading them until they break, and carefully noting the weight under which they give way. For large cast-

ings this system would prove too expensive; small bars are therefore cast from the same metal and at the same time as the castings, which are tested to fracture by a weight applied to the centre. These test bars are usually 3 feet 6 inches long, 2 inches deep, and 1 inch wide, with a clear bearing of 3 feet. The test weight varies, according to the opinion of the engineer, from 25 cwt. to 30 cwt., the general test, however, being 28 cwt. It is of course important not only to ascertain the breaking weight of the bar, but also the amount of deflection before fracture, for the reason that a very hard iron will sometimes bear a very high cross strain when steadily applied, although it would be too brittle and inelastic for any position in which it would be liable to vibration or shocks of any kind. There is an excess of about 16 per cent. in the weight that a 2-inch by 1-inch bar will support when cast on edge and proved in that position, over that which it will support when proved with the underside, as cast, placed at the top. Hence cast-iron girders should be cast with the tension-flange downward in the sand.

The cast-iron sleepers for the Great Indian Peninsula Railway were tested by a falling weight of $3\frac{3}{4}$ cwt. from a height of 5 feet 6 inches, on sand not more than 2 feet deep, and test bars were broken by a cross strain of 28 cwt. to 30 cwt., with a deflection of not less than five-sixteenths of an inch.

Molesworth gives the following tests for cast iron, as a mean taken from fifty-one samples:—

	Tensile.	Transverse.	Torsion.	Compression.
Lbs. per sq. inch ..	23,257	7,102	6,056	91,961
Tons	10·382	3·170	2·703	40·652

Although the practice of test bars may be a useful means of showing the strength and elasticity of the iron, inspectors should bear in mind that this is not the only way, or perhaps even the best way, of judging the true nature of the iron. The general appearance of the casting should be taken into consideration, and especially the grain of the iron on the runner should be carefully examined, for here it will be found pure and free from sand or other foreign bodies. The quality and brand of the pig used, the proportion of "scrap," and the general conduct of the shop, especially when the actual casting takes place, are all points which will serve to assist inspectors in their duties, which should be performed in a scrupulous

and exacting manner, in these days when competition has driven down prices to such a level as to often induce unscrupulous founders to tender at a price for which it is practically impossible to produce other than an indifferent quality of work.

DISCUSSION.

The PRESIDENT said they had listened to a long, exhaustive, but very ably-written paper. Every branch of engineering was indebted in a greater or less degree to the work of the foundry. The paper gave a record of what was known, as well as the statement of new information which the author had added; and the paper was an important contribution to the 'Transactions' of the Society. He begged, in the name of the Society, to thank the author for the communication.

Mr. HENRY ADAMS said that the paper to which they had listened might be described as a fairly complete elementary treatise upon foundry practice, and as such it was specially valuable to the younger members of the Society. Among the woods suitable for pattern making the author had not specified the American white pine, or *Pinus strobus*. This was generally considered a most suitable wood for ordinary patterns, on account of its uniformity of grain and freedom from knots; it was, however, very subject to dry rot. A wood which was not so well known as it deserved to be, was the Kauri pine of New Zealand (*Damara Australis*). It was harder than American pine, but very uniform in grain and could be obtained in large sizes, although it was best adapted for patterns for brass work and small core boxes. It would cut almost equally well in both directions, and was suitable for other purposes besides pattern-making. The average of $\frac{1}{96}$ given for the shrinkage of cast-iron, was only a general average; there were special cases in which the amount of shrinkage which was allowed for in a pattern must be that indicated by experience. The twistings of castings of certain shapes, such as the blades of propellers, formed an interesting branch of this study. As to the withdrawal of the plug C, it was not clear to him why the air should strike downwards as described by the author. With regard to one of the columns shown in the diagrams; if it was intended to be without a curve under the fillet as drawn, the pillar deserved to break through either A or B, and it would require a little modification to make it passable as an engineer's column. A material called "beaumonteque" had been referred to; they had of course none of them ever seen it, and it was a little reassuring to find that it

was of German origin, being a corruption of the term "Baumantik," a composition used originally only by cabinet makers to make up for the deficiencies of nature. The press cylinders which had been spoken of, had been described as having been tested to four or five times their working pressure; the practice of Sir William Armstrong and Co. was to test to three times the working pressure; that was the usual practice among hydraulic engineers, and he thought that it might be looked upon as sufficient for the purpose of finding out weak castings.

Mr. J. W. Wilson, Junr., said the paper was none the less valuable because it went over familiar ground. A form of foundry work which was interesting to the civil engineer was the casting of large iron pipes for water supply, &c., but they had not heard very much about this in the paper. In diagram 5 there was a representation of the mode of forming iron pipe cores, but he should like to supplement what the author had said by mentioning that in large pipes of 10 or 12 feet in length and 30 to 40 inches in diameter, such as had of late been used for the Liverpool Waterworks, a process was employed in the foundry where they were cast, of drawing-in the segments of the core after the metal had been poured into the mould. The iron centres of the pipe cores had four overlapping joints running down from end to end, and by means of the application of a screw, running transversely down the centre, these segments could be drawn together inwards, and thus relief could be given just at the moment when it was found to be needed. It was certainly of great importance to have such articles as water pipes cast in a vertical position, but although it was very well to say that a "dead head" should be prepared for in a pattern, he had seen cases in which the dead head turned out to be the best part of the casting, in consequence of its not having been placed at the top. In matters such as these, inspection was evidently necessary, and he agreed that a great responsibility rested upon the inspectors. If they were not present at the time of casting, mysterious matters such as the author had alluded to, and others of a kindred nature, would sometimes be found to exist. In the case of pipes, the tensile and transverse tests were not the only matters of the kind worthy of attention. As regards the pipes already alluded to, the founders could produce cast iron which would stand a very high tensile test, even higher than was required by the ordinary conditions of the engineer's specification. They, however, as engineers, did not consider that that must necessarily be the best iron for the purpose. They attached much importance to the actual testing of the pipes after they had been trimmed up and run out to the testing machine. In connection with the

subject he might mention that some specifications required that the testing should be carried out under pressure from coal tar oil instead of water, and that this appeared to give very satisfactory results. He did not know whether that method was a common one. There were obviously many subjects which could be brought forward in the course of such a discussion on subjects which the author had not included in his paper. It was easy to say that this or that matter was not included; but no paper could attempt to deal with everything connected with the subject. He wished in conclusion to state, that in his opinion if there was one form of practical experience more important to an engineer than another, it was perhaps that of pattern making and foundry work.

Mr. WILLIAM SCHÖNHEYDER said, it was evident that the author was thoroughly at home in the subject. If there was any fault it was perhaps that the paper was a little too elementary. As to the scrap iron alluded to by the author, that was always a weak point in foundry work; the same remark applied to gun metal scrap, they never knew what scrap consisted of, unless it was broken up and sorted; it might comprise the worst descriptions of metal, and the best intentions of the founder might be spoiled in consequence. With reference to Figs. 1 and 2 in the diagrams, he should like to ask the author whether the crystals, which were there represented as being formed in a particular manner, were merely theoretical, or whether the iron had been actually examined under a microscope and the form of crystallisation observed. Quite apart from the formation of crystals, a piece of work such as shown in Fig. 1 would be weak in itself, even though the casting might be perfectly solid, and would give way at the corners under hydraulic pressure. Shrinkage had been already well alluded to, it was well known that various forms of castings, such as wheels, long girders, thin girders, and engine beams, had different rates of shrinkage which only actual practice could deal with. If the founder had an entirely new form of casting, it would be impossible to foretell exactly what the shrinkage would be. He had not heard any allusion made to the effects of shrinkage in the cast drum shown at Fig. 7; if the arms of the drum were thinner in section, and therefore cooled quicker than the outside drum, they would be seriously compressed, and unless some provision was made to combat this effect, they would be subject to very heavy stresses, which might ultimately cause fracture, and although apparently sound at first, they might soon break after being set to work. As to the mode of making iron "malleable," he should like the author to give them the chemical reason why the iron became

soft when treated in the manner which he had stated. In connection with the drying stoves, it had not been stated where the escape for the hot air and vapour should be; in his opinion it should be near the floor, so that the coolest air would always be removed and the hottest remain behind. As to Fig. 4, he did not think that the reason why the plug should not be removed first was to prevent the air from escaping; it was rather to prevent the metal from escaping, and therefore to compel the air to pass out through the pores of the mould. With regard to testing, it was hardly correct to say that a casting should be tested to three or four times the working strain, the test depended upon what the working load was to be; when the working load was to be high, the casting should never be tested to the amount of three or four times. The same principle applied to the testing of boilers.

Mr. W. F. Pettigrew, referring to Figures 1 and 2, said that it was very important that there should not be any sharp angles. He believed that all pattern makers knew very well that it was wrong to make a sharp angle. In turning cast-iron it was very important to make a proper radius in the corner of the work. The New Zealand wood which had been alluded to by a previous speaker, had been often used by him (Mr. Pettigrew), during fourteen years, and he had found it the best wood possible for good sound patterns. One important thing in the casting of iron was that a surface which required machining should always be at the bottom of the mould. The author had not referred to moulding machines; at the present day they had to mould a great many things from one pattern and they should always have moulding machines. Of these there were several kinds in the market. On the subject of testing, he agreed with the last speaker that it would be a great mistake to test to three or four times the working pressure, when that pressure was to be a high one. He could mention cases in which the test was only double the working pressure, and some locomotive tests were only $1\frac{1}{2}$ times the working pressure. About a month ago he had a 4-inch steam pipe taken out, the thickness of which should have been $\frac{1}{2}$ inch all round, but it was found that the thickness was only $\frac{1}{16}$ inch on one side, while on the other it was, of course, nearly 1 inch. The pipe had been at work for ten years and had never given out, but it is impossible that this pipe could have been properly tested in the first instance. The author had not mentioned the twist which had to be allowed in the casting of long lengths, such as gutters for houses. This was a very important point. The pattern had to be made on the twist, so that when the casting contracted

it became straight. He had used both kinds of cupola bottoms, but he certainly thought that the drop bottom was the best. It effected a great saving in the time of the men at night, when the metal was out, and in the morning it saved time in putting the cupola in order again. As to drying stoves, it was very old fashioned to have a fire inside, the practice now was to have air pipes running round. It was also customary in all foundries to have mechanical sand sifters. Some sand was very loamy and some was sharp; it was mixed first of all in a small mill and then passed through a mechanical sifter. After the sand was properly ground in the mill it was put into the sand sifter and sifted to the right size. Of course it was important to have the right kind of sand. As to cranes, it was desirable to have steam swing cranes instead of overhead travellers, one reason being that it was very difficult to get men to work on overhead travellers. He expected that the author would have given them some particulars as to the amount of coke required per cwt. or per ton of iron, as the amount differed very much in different cupolas. He had found that, including the making of the bed in the first place (an item which was often forgotten), about 10 lbs. of coke per cwt. of iron was a very good rule. Without the making of the bed, about 6½ lbs. of coke would be required. In a cupola of 3 feet 6 inches in the largest diameter, and 2 feet 6 inches in the smallest, he could easily melt 8 tons of iron per hour. In reply to Mr. Schönheyder, the speaker added that he used a blast of 1½ inch (mercury) for that quantity per hour.

Mr. George A. Goodwin said that the subject of the testing of cast iron bars was, even up to date, not fully understood, and therefore well worthy further investigation. It was well known that very different results in the strength of the bars was obtained when made in different localities, and for reasons not generally known. The author had stated that the average transverse strength was 28 to 32 cwt. on a 2-inch by 1-inch bar placed on bearings 3 feet apart. That Mr. Goodwin considered to be a very good quality of iron, providing the deflection amounted to about ·4 inch. He had lately had some 2-inch by 1-inch iron bars tested in Glasgow, which gave the remarkable result of 40 cwt. breaking weight, with a deflection of ·3 to ·4 inch. With regard to the fettling of castings, it had often occurred to him that a very good and useful tool might be made by the combination of an emery wheel working on a spindle, with handles at each end, and rotated by means of a flexible spiral spring shaft. It could easily be held up against any projections that were required to

be taken off, and save a lot of chipping, with the frequent consequence of making indentations in the casting. He had had considerable experience in cast iron work, and had very frequently found defects such as sand, scoria, ashes, or blow-holes existing; the heads put on castings while being cast did not always prevent the occurrence of such defects, nor did he think it was of much use as regarded the extra fluid pressure it produced, for 12 inches of head represented only 3·13 lb. per square inch; nor did such heads always succeed in getting rid of dirt, the solid or foreign matter lodged at the sides of the mould or wherever any projections occurred, and so could not get away. To overcome this he had designed a ladle which drew the molten metal from the bottom, while maintaining the advantage of pouring it into the mould from the top, and in effect acting as an automatic skimming bottom pouring ladle. The speaker then went on to describe in detail the construction of the ladle, stating the body, instead of being circular as usual, was pear-shaped or extended on one side to form the pouring spout, the circular part was then continued across the spout by means of a removable division or skimmer plate, attached at the top by pins and cotters to the outside of the shell, and by fingers or cleats at the bottom inside the shell. This plate projected above the top of the ladle, and ended short at the bottom by an amount equal to about one-quarter the depth of the ladle, this division plate being prepared by suitable iron strips and perforations, so as to hold the refractory lining which was put in on both sides. In using the ladle, it was not necessary to skim, and the surface of the metal in the body of the ladle could be, if required, kept hot by the usual covering of sand, ashes, wood, &c., while pouring; and in cases of slips or jerks, no foreign matter could get over the top of the division plate and into the mould. The hottest and densest metal was poured first—which was very important—and the lightest and most impure was left in the ladle with ashes and scoria floating on it. A further small advantage was that the impurities not having to be raked off on to the moulding floor, much time and trouble is saved in the after cleaning and sifting the sand. The ladle had been in use for about three years with very satisfactory results. In casting some large gas holder columns, owing to the large ornamental capitals, large heads were required, which unfortunately resulted in many of them cracking owing to the unequal cooling of head and capital; but when cast with his ladle, the heads were reduced from 8 inches to $1\frac{1}{2}$ inch, with the result that no further failures took place. Cylinders had been cast with his ladle without heads at all and given most satisfactory results.

Mr. Perry F. Nursey said that if those speakers who had said the paper was too elementary, and that the author had made various omissions, would reflect, they would see that any one of the subjects treated of would afford material in itself for a long and interesting paper; and even then much matter of an elementary character would have to be introduced to lead up to and explain what followed. He would suggest that the author should be asked to give the Society at some future time a paper on the higher branches of foundry practice, of which there was much to be said. The idea of the emery wheel of which Mr. Goodwin had just spoken had also occurred to him (Mr. Nursey), and he had thought that it would prove a very useful tool to the founder.

Mr. H. Sherley Price thought that the paper to which they had listened that evening only referred to what might be termed the elements of general foundry practice, and said that the cupola shown in the diagram had been practically discarded for many years by most firms. He regretted that there was nothing said in the paper regarding machine moulding, which in these days of competition was very important as a means of saving labour; also, no reference had been made to modern cupola practice, pressure of blast, coke used per ton of metal cast, and other important matters upon which greatly depended success or failure in iron-founding.

Mr. E. M. Barton asked what was the result of the author's experience with bed plates for large bridges, cast with the working faces vertical. It seemed to him that the better plan was to cast the working faces downwards.

Mr. C. Hemsworth said that he believed that the author had said that the plug K (Fig. 5) was provided to prevent the air from passing downwards, but he (Mr. Hemsworth) thought that this was not the correct idea, but that it was rather to prevent the rush of air making its escape through the orifice, before the mould was filled up, bringing down the face of the mould and thereby causing scabs. With regard to Fig. 7, it was not necessary in the proper castings of a pipe or barrel that the core of the pipe should be extracted. One of the chief reasons why the hayband was put round the barrel was that when the hayband was burnt it allowed the loam surface to contract. It was the common practice in foundries where only one casting of a pipe or column was wanted, to strike up the core, drying and blacking it afterwards, and then the block and the pattern were struck up on the same column, moulded, and the cast made from it. With regard to Fig. 1, he believed that the reason of the weakness of that form was that the weak and coarse metal generally flows into the corners.

He believed that this had more to do with the peculiar contraction of the metal than with the general grain of the metal or with the particular form of the pattern.

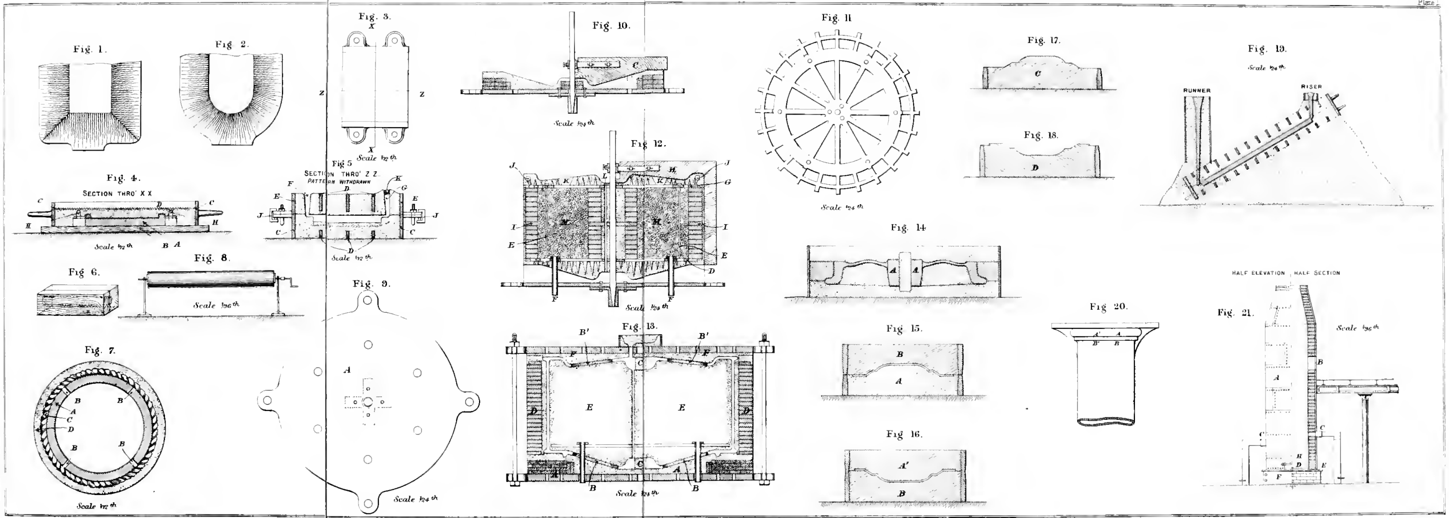
Mr. Thomas Stevens said that he had not heard any gentleman mention sycamore wood for patterns. That was a very good wood for the purpose. It worked nicely, it was an English wood and it was not very expensive, and it is not very liable to warp or shrink and will take glue very well. He wished to ask the author what was the weight of the drum which he had described.

The President, in calling upon the author to reply to the discussion, said that if he would like to reserve any part of his answer to be given in writing he would be at liberty to do so.

The Author, in reply, stated that the course he had endeavoured to pursue throughout the paper was, to set forth the primary outlines of foundry work as applicable to the ordinary branches of moulding and casting, necessary for every civil engineer to thoroughly understand. It was impossible, in dealing with such a wide subject, to do much more than sketch the constituent principles of cast-iron work, and to follow the different stages through which the iron passes before it reaches the final stage of completion. A good deal of discussion had arisen as to the necessity of the plug of loam K in Fig. 5. When the molten metal is poured into the mould it instantly generates a large amount of gas, caused by the oxidising of the coal dust and the burning of other combustible matter in the sand, which would rush out of the orifice G (Fig. 5), causing an undue pressure of air on the top of the mould, and thus tending to detach particles of sand, which would fall into the mould; but by plugging up this passage the gases would be forced to strike "up" through the pores of the sand, while any dirt would rise into the flow-gate. Mr. Adams had suggested that the column shown in Fig. 20 required some modification to make it passable as an engineer's column; the author could, however, only state that the sketch of the column was an exact copy of one designed for the Albert Docks, and that when he (the author) had last seen it, it was carrying out the object for which it had been intended. With regard to the testing of cast-iron pipes, the author was inclined to agree with those speakers who had suggested that about three times the working pressure was a sufficient test, it being borne in mind that the testing of cast iron was a very different thing from the testing of boilers or wrought iron generally. He regretted that Mr. J. W. Wilson, junr., had not mentioned the individual

advantages arising from the use of coal tar oil instead of water, for it seemed to be rather a nasty stuff to deal with. In answer to Mr. Schönheyder as to the particular formation of the crystals on the cooling of the metal, microscopical examination had shown that the crystals did place themselves at right angles to the exterior and interior surfaces, and hence the necessity of curving as far as possible all sharp corners and angles. Allowance was made for the shrinkage of the drum (Fig. 13), by making the edges of the top and bottom plates used in the core (Fig. 11), in the form of spokes, whereby the loam is able to draw away when the metal commences to contract. The arms of the drum were of the same thickness as the body, thereby effecting a uniform contraction of the entire casting. The weight of the drum was just upon 1 ton. The chemical action set up in the iron during the process of rendering it malleable is as follows: the graphite carbon first passes into the non-graphite or combined state, and is subsequently converted into carbonic oxide, either directly by the oxygen of the blast, or indirectly by the action of the oxide of iron in the slags. In many instances this oxidising agent is supplied by the iron itself, which is always to a certain extent oxidised by the air from the blast during the process of fusion; while with others it is directly added in the form of powdered hæmatite ore, forge scales, or finery-cinder, as before described. The author fails to understand how Mr. Pettigrew by the use of the drop bottom to a cupola saved time in the morning; he was ready to allow that a little time was saved in the evening, after the casting had been performed, but on the following day the drop bottom would require to be relined and dried, an operation unnecessary with the old pattern of cupola. Mr. G. A. Goodwin had brought before the notice of the Society an automatic skimming ladle of his own design which was very superior to the ordinary old-fashioned type; but the author was a little inclined to think that the inventor had slightly overrated its value. He (Mr. Goodwin) had mentioned the satisfactory results from casting some large gas-holder columns with large ornamental capitals, which he attributed to the adoption of his particular form of ladle. The previous causes of failure, he says, arose from cracking owing to the unequal cooling of the head and capital; now the contraction of the metal is due to its own natural causes, and no design of ladle could possible obviate this failure; it can only be remedied by a careful attention being paid to the feeding to supply the contracting parts, not to mention the fact that it is generally considered advisable in the case of large ornamental capitals to cast the column and ornamental

parts separately. In answer to Mr. E. M. Barton as to the result of casting rockers for large girders with the working surfaces vertical, the author could only state that he had seen very satisfactory castings turned out by adopting this method. In conclusion, the author begged to tender his thanks for the valuable information which the various speakers had contributed towards the subject of his paper during the discussion.



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December 3rd, 1888.

ARTHUR T. WALMISLEY, PRESIDENT, IN THE CHAIR.

HIGH PRESSURE STEAM AND STEAM ENGINE EFFICIENCY.

BY W. WORBY BEAUMONT, M. INST. C.E.

THE advocacy of high-pressure steam has been based on various grounds, but generally the arguments in its favour have been met by others almost equally convincing against it, and chiefly based on the principle that the utmost efficiency which can be obtained from the steam engine as a heat engine, depends upon the relation which the absolute temperatures between which it is worked bear to the whole absolute temperature. Various standards or indexes of efficiency have been proposed and used, and all have indicated that some advantage thermodynamically, should attend the use of high-pressure steam. None have, however, indicated so great an increase in efficiency as that which has actually resulted from the use of the higher pressures now becoming common.

No engine has ever given, or ever will give as work, more than a fraction of that represented by the heat carried by the steam supplied to it, but the increase in the economic efficiency which has attended the use of high pressures and multiple stage expansion, has been more than was anticipated from thermodynamic considerations. As one illustration of this, among many, reference may be made to the report to the Royal Agricultural Society, by Sir Frederick Bramwell and Mr. W. Anderson, M. M. Inst. C.E., on the engine trials at Cardiff in 1872, and at Newcastle in 1887. Comparison is made in this report between the Reading Ironworks engine at Cardiff, using steam at 80 lb. pressure, and Davey, Paxman, & Co's simple and compound engines at Newcastle, using steam at 95 lb. and at 150 lb. The report says, "the advantage derived from using higher pressure steam is a consequence of its higher temperature," and as an index of the improvement to be expected, the proportion which the fall in temperature bears to the original absolute temperature, or the comparative

efficiency $E = \frac{T - t}{T}$, T and t being absolute temperatures, was used. The following table, giving the comparison, is published in the report:—

TABLE VI.—COMPARISON BETWEEN THE THEORETICAL AND ACTUAL ECONOMY DERIVED FROM AN INCREASE OF STEAM PRESSURE.

	Cardiff.	Newcastle-on-Tyne.	
	Reading Ironworks. Simple.	Davey, Paxman, and Co. Simple.	Davey, Paxman, and Co. Compound.
1. Steam pressures above atmosphere lbs.	80	95	150
2. Temperature of steam .. .. F.°	324	334	365
3. Corresponding absolute temperatures .. .. F.°	784	794	825
4. Falls of temperature to 215° or 675° absolute .. .. F.°	109	119	150
5. Proportions which the falls bear to the original absolute temperatures	0·139	0·150	0·182
6. The reciprocals of the above ratios, to which reciprocals the fuel actually consumed should correspond, reduced to the Reading engine as uuity	1	0·927	0·763
7. Water actually consumed per brake horse-power per hour (not including jacket-water) .. lbs.	30·22	26·40	21·33
8. Relative proportion of water used ..	1	0·873	0·706

Concerning these results the report says:—

"We see that Messrs. Davey, Paxman, and Co.'s simple engine should have demanded about 7 per cent. less steam, and their compound $23\frac{1}{2}$ per cent. less, than the Reading Ironworks engine. In reality their simple engine, as will be seen by the eighth line, took 13 per cent. less, while the compound took nearly 30 per cent. less, than the Reading Ironworks engine."

That is to say, then, that imperfect as the steam engine is, the improvement resulting from the use of high pressures is considerably greater than theory would indicate as possible, reference being made to the best result obtained with lower pressures. Theory does not indicate that the improvement should result from expanding in two stages instead of one, and therefore that need not here be dealt with as one of the reasons. In conclusion, upon this part of the subject the report adds:—

"From the foregoing it is clear that it must not be hastily assumed that an indefinite amount of economy is to be derived

from the use of higher pressures. The increase in the temperature of steam does not correspond to the increase in pressure, but rises more slowly than the pressure increases, thus :—

From boiling point to	50 lb.,			temperature	rises	88	degrees.
,,	50 lb.	to	100 ,,	,,	,,	38	,,
,,	100	,,	150 ,,	,,	,,	29	,,
,,	150	,,	200 ,,	,,	,,	20	,,
,,	200	,,	250 ,,	,,	,,	18	,,

and consequently the fall of temperature in working bears a smaller proportion to the fall of pressure, and all the mechanical difficulties connected with high-pressure steam have to be grappled with, for, it may be, inadequate gain. The trials appear to point to the conclusion that, with our present state of knowledge, it is probable that pressures between 150 lb. and 200 lb. per square inch will give the best practical results."

This examination of the question, then, proceeds entirely on the supposition that the greater economic efficiency of the high pressure steam is due to the higher temperature.

As commonly used, the Carnot function is misapplied. It is not in fact usefully applicable in that form at all to any question of efficiency of steam in a steam engine cylinder. It has for a long time been used in the manner herein already indicated, and on the supposition that it gave a comparative index of the greatest possible amount of work performable by two engines working between two different ranges of temperature. The author has shown that this is far from being the case, and Professor Unwin, F.R.S., in his recent address to the Junior Engineering Society, dwelt upon the subject and reminded his hearers that only the hypothetical perfectly-reversible engine, from which the steam engine is as far removed as the limited from the limitless, can convert the fraction $\frac{T - t}{T}$ into work. It must not, however, be supposed that any doubt is thrown upon the Carnot theorem. Attention is only drawn to its general misapplication, which has led engineers to assume that, according to Carnot, increase in temperature of steam ought to be attended with a directly proportional increase in obtainable work. Carnot's theorem is beautifully simple, but the conditions* attending it make it of small service in steam engine matters.

The object of this paper is to enquire whether there are not ample reasons theoretically for expecting that very *large* gain

* Completely set forth in 'Clausius' Mechanical Theory of Heat,' by W. R. Browne, pp. 276–288.

should attend every increase in pressure up to at least 300 lb. per square inch; and, secondly, to offer for discussion some suggestions concerning cylinder condensation, and the greatest quantity of work possibly obtainable by means of a steam engine from a given quantity of steam. It is proposed to show that the conversion of heat into work during performance of work is, with small additions for radiation, conduction, clearance, and evaporation during exhaust, sufficient to account for cylinder condensation. Whether we take the work thermodynamically due from the heat units in 1 lb. of steam, as usually estimated, and compare this with the work actually obtained; or whether, according to the doctrine of Carnot, we compare the fall in temperature of the steam while in the engine with the original absolute uniform temperature of receipt, we deal with some heat which cannot be employed by the actual steam engine as heat convertible into work.

Below the temperature due to the terminal pressure in the cylinder, no modification can materially affect the performance of the steam in doing work. On the other hand, the quantity of work that can be obtained from 1 lb. of steam at any given pressure during admission, or up to the point of cut-off, is a definite quantity. The only period, then, during which any material modification can be made in the employment of steam, is that between cut-off and exhaust, or the part of the stroke during which the expansive energy of the steam is employed. But as it is desired to compare the work done by 1 lb. of steam at different pressures, but with ranges of expansion producing similar falls in pressure, that part of the history of the steam must be taken which includes admission and expansion. If it be desired to ascertain the value of the work that can be obtained from steam at a high pressure, as compared with the value of the work that can be obtained from steam at a lower pressure, the difference between the quantity of heat required to produce the steam at the two pressures should be employed. To say this appears to be to utter a common-place, but whether it be so or not, the course suggested is not that which is usually adopted. The relative possible efficiency of 1 lb. of steam at a higher and at a lower pressure is not represented by the relation between the total heat at the two pressures.

If a non-condensing engine be supplied with steam at 212° F., the total heat of 1 lb. of which is 1146·6 units, the engine will be incapable of converting any of the heat into work.

If, on the other hand, the engine be supplied with steam at say 298°, the total heat of 1 lb. of which is 1172·7 units, (or 26 units more than in the steam at 15 lbs. pressure) it will be able to perform 135,400 foot-lbs. of work, assuming the volume

before expansion and at atmospheric pressure to be those of dry saturated steam, and that the expansion takes place adiabatically, or on the assumption that $P V^{\frac{10}{9}}$ = a constant.

The methods of calculation usually adopted for finding the heat units convertible into work from 1 lb. of the steam which must be actually passed into a steam-engine cylinder, appear to give a greater mechanical value to 1 lb. of steam than is thermodynamically due from it. It is not necessary, however, to review the various methods. That which is now proposed may be at once set forth. Four assumptions must be stated:—

1. When a quantity of steam at given pressure and volume is admitted into a cylinder, a piston in which is capable of being moved by it, and then expands from that volume to a larger one, and to a lower pressure, it is supposed to be capable of performing work equivalent to the sum of the original volume plus the increase in volume multiplied by the area of the piston and by the mean pressure acting upon it.

2. When such a quantity of work is so performed, it is supposed that one unit of heat disappears for every 772 foot-lbs. of that work.

3. The pressures will be assumed, between the initial and terminal volumes, to vary inversely as the volumes, or P V will be assumed to be a constant, and the necessary correction as to heat required to meet this assumption will be afterwards made.

4. That the work done in a cylinder during admission results in a disappearance of heat which causes liquefaction; that this liquefaction will generally take place in the cylinder although the work done during admission is the external work of evaporation.

Of the first proposition there is no doubt, although there may be some doubt as to the method of measuring or estimating the disappearance of heat. If, however, the second proposition be granted, then it appears that the first proposition demands an extraneous supply of heat equivalent to the whole of the work or nearly all the work measured in accordance with it; for it is much greater than the mechanical equivalent of the heat which is given up by the assumed original volume of steam during expansion. In the actual steam-engine this heat is provided by the quantity of steam which is used in excess of that which is necessary to fill the cylinder.

It will be sufficient for the objects mentioned, as well as to show the increase in efficiency and economy due from the use of steam at high pressures, to take for numerical examples steam at five pressures. Only non-condensing engines will be at first considered, as the value of expansion to pressures below that of

the atmosphere, will be very nearly a constant quantity, whether steam at 50 lbs. or at 300 lbs. be used.

The terminal pressure, P t, will then in each case be taken as 15 lbs. per square inch, and as a first example 65 lbs. will be taken as the maximum pressure, P, that being taken because a pressure of 50 lbs. per square inch above atmospheric pressure is a pressure which has been or was for a long period common, in simple as well as compound engines. The quantity of steam theoretically required per horse-power per hour at this pressure, at 100 lbs., 150 lbs., 200 lbs., and 300 lbs. per square inch are given in the annexed table, with the work to be expected from 1 lb. of steam at each pressure.

When 1 lb. of water is heated and converted into 1 lb. of steam under constant pressure, a small quantity of the whole of the heat used is employed in performing external work. It is assumed that when evaporation takes place under constant volume, instead of under constant pressure, the heat required is less by the equivalent of that amount of external work. Whether this is so or not, is a matter of small importance, except that a steam-boiler is during at least half its time, evaporating at constant volume, for admission to the cylinder of the steam-engine supplied rarely takes place through more than half stroke. In slow-running engines, the assumption may be of more importance than in quick-running engines, as the higher the rotative speed the more nearly will the conditions of evaporation under constant pressure be approached.

For the purposes of this paper it will, however, be assumed that evaporation takes place under constant pressure. Under this assumption the work done upon the piston of a steam-engine up to the point of cut-off, is the external work done during evaporation. With reference to the quantity of steam used by an engine, the question arises, What is the nature of the effect of this performance of external work, an effect which results in the disappearance of a few units of heat? The easiest supposition is that the performance of this external work during evaporation, results in a cooling and consequent liquefaction, and that the further quantity of heat which is used is employed in re-evaporation. Heat is not directly converted into mechanical energy; but indirectly through its conversion of water into steam.

If this be the nature of the *modus operandi* of the conversion of heat into the motion of the piston, it is allowable to suppose that the liquefaction will take place in the cylinder, which in ordinary cases is separated from the boiler by a pipe or passage. If this supposition be allowed, then the heat represented by the external work of evaporation will, in the case of the actual

engine, be employed in evaporating more water in the boiler, instead of re-evaporting steam liquefied in the performance of that external work of evaporation. The total heat of evaporation will remain the same, but a quantity of water will have to be fed into the boiler to make up for the water rejected from the cylinder. Now by assuming this liquefaction to take place in the cylinder, and that in quantity it represents the whole of the external work of evaporation, then the steam in the cylinder of a non-expansive engine at the end of a stroke must, as a minimum, be that necessary to fill the cylinder minus the space occupied by the steam thus liquefied. There will thus have passed into the cylinder the quantity of steam necessary to fill it plus that which, by its liquefaction, will have given up of latent heat the number of units which represents the work done, or the external work of evaporation.

Thus for arriving at the minimum quantity of steam that will be used by a steam-engine, or at the number of units of heat due from 1 lb. of steam in the form of work, we may proceed on the assumption that in addition to the steam necessary to fill the cylinder, so much will be required as will by its liquefaction give up latent heat sufficient to represent the whole of the work done, whether the engine be expansive or non-expansive. Thus, while crediting the boiler with evaporation under constant pressure, and therefore with the performance of the work done up to cut-off, it is assumed that the result of that performance of work is liquefaction in the cylinder, and the steam that will be passed into the cylinder may be calculated just as though evaporation were performed at constant volume, or as though it were that necessary to fill the cylinder at the pressures shown by an indicator diagram, and to provide heat units sufficient to represent the work done on the piston.

In passing, it may be remarked that if this be not a permissible assumption, then as an improvement in obtaining economical steam-power, measures should be taken by means of which all the steam used should be generated at constant volume.

For the purpose of these calculations the following symbols will be used.

- V = Volume of 1 lb. of saturated steam at initial pressure P.
- V_1 = Volume of 1 lb. of saturated steam at terminal pressure $P\,t$.
- T = Temperature of steam, absolute, at pressure P.
- t = Temperature of steam, absolute, at pressure $P\,t$.
- H = Total heat of 1 lb. of steam from 32° at pressure P.

h = Total heat of 1 lb. of steam from 32° at pressure P t.
L = Latent heat of steam at pressure P.
L_1 = Latent heat of steam at pressure P t.
P = Total initial pressure of steam.
P m = Mean pressure.
P t = Total terminal pressure of steam.
R = Range of expansion $\frac{V_1}{V}$.
W = Work in foot-lbs., represented by admission of volume V and isothermal expansion to volume V_1 under mean pressure P m.
W_1 = Work in foot-lbs. done against atmosphere or against back pressure.
W_{11} = Available work in foot-lbs. = W − W_1.
U = Units of heat corresponding to work W.
W s = Work in foot-lbs. available per 1 lb. of steam used.
S = Steam theoretically required per horse-power hour.
S_1 = Weight of steam theoretically required to perform W and to provide U, or weight of steam actually necessary for every 1 lb. shown by the indicator diagram at release.

$$S_1 = 1 + \left(\frac{\frac{W}{J} - (H - h)}{L}\right)$$

or more correctly

$$S_1 = 1 + \left(\frac{\frac{W}{J} - (H - h)}{L}\right) - \left(\frac{T - t}{L_1} \times \frac{\frac{W}{J} - (H - h),}{L}\right)$$

and

$$W\,s = \frac{W_{11}}{1 + \left(\frac{\frac{W}{J} - (H - h)}{L}\right)}$$

or more correctly

$$W\,s = \frac{W_{11}}{1 + \left(\frac{\frac{W}{J} - (H - h)}{L}\right) - \left(\frac{T - t}{L_1} \times \frac{\frac{W}{J} - (H - h)}{L}\right)}$$

By putting $U_1 = H - h$, and $U_{11} = U - U_1$, then

$$S_1 = 1 + \left(\frac{U - U_1}{L}\right) - \left(\frac{T - t}{L_1} \times \frac{U\,U_1}{L}\right) =$$

$$1 + \frac{U_{11}}{L} - \left(\frac{T - t}{L_1} \times \frac{U_{11}}{L}\right)$$

or approximately

$$S_1 = 1 + \frac{U_{11}}{L} \quad \text{and} \quad Ws = 1 + \frac{\dfrac{W_{11}}{U_{11}}}{L}$$

$$\text{If } s = \frac{U_{11}}{L} \quad \text{then} \quad S_1 = 1 + s - \left(\frac{T - t}{L_1} \times s\right)$$

and

$$Ws = \frac{W_{11}}{1 + s \times \left(\dfrac{T - t}{L_1} \times s\right)}$$

or approximately

$$Ws = \frac{W_{11}}{1 + s} \quad \text{and} \quad S = \frac{33000 \times 60}{Ws}.$$

Taking 1 lb. of steam at 65 lbs. total pressure P, expanded isothermally, to volume corresponding to 1 lb. of steam at 15 lbs. $= P\,t$, the ratio of expansion $R = 3 \cdot 98$, and the mean pressure $P\,m = 38 \cdot 7$ lbs. The volume, V, of the 1 lb. of steam at pressure $P = 6 \cdot 49$ cubic feet and of that at 15 lbs. the volume $V_1 = 24 \cdot 25$. The total work W represented by the admission and expansion of the 1 lb. of steam will then be $V_1\,P\,m \times 144 = 144{,}250$ foot-lbs. This is equivalent to $U = \frac{W}{J} = 186 \cdot 8$ heat units; but as this number of heat units is very much greater than the difference between the total heat of steam at 65 lbs. and that at 15 lbs., at which the steam leaves the cylinder, one of two things must take place: either a much smaller quantity of work will have been performed, and heat instead of being converted into work will have been used in keeping the steam up to the temperature proper to the assumed terminal pressure and volume; or the steam must have received heat from an extraneous source sufficient to prevent liquefaction. If neither of these are assumed, then it must be supposed that initial condensation has taken place, sufficient liquefaction having occurred to supply the deficiency by giving up latent heat.

If the total work W be calculated by assuming adiabatic

expansion, it will be lessened as shown on the Table, and the quantity of steam liquefied will be shown by the difference in the volumes V_1, after adiabatic and after isothermal expansion to the volumes proper to the assumed terminal pressure. But even with this lessened quantity of work done there is not sufficient heat given up to account for it. Hence a greater quantity of steam must be liquefied than is allowed for, when it is assumed that under adiabatic conditions of expansion the pressure varies as the reciprocal of the tenth power of the ninth root of the space occupied; that is to say, the pressure must fall much more rapidly than is represented by an adiabatic expansion curve so calculated.*

The total heat H of steam at pressure $P = 65$ lbs. $= 1172 \cdot 76$, and the total heat h at pressure $P\,t = 1146 \cdot 7$, hence the heat given up by the steam up to the moment of exhaust $= H - h = U_1 = 26$. Thus U_1 is considerably less than U, and this deficiency $U_{11} = U - U_1 = 186 \cdot 8 - 26 = 160 \cdot 8$.

That is to say, if heat disappears in proportion to W the work done, this quantity $U_{11} = 160 \cdot 8$ units must be imparted to the 1 lb. of steam, in order that it may remain as steam at the calculated pressures and volumes, or to meet the assumption of isothermal expansion with performance of work. Now for the supply of this heat, the easiest and probably the most correct assumption that can be made is that it is to be found in the latent heat of steam condensed during admission, partly as a result of the entrance of the high pressure steam into a cylinder cooled by evaporation during the previous expansion and exhaust strokes, and partly by liquefaction consequent upon performance of work during admission. The steam thus condensed initially and during admission, whether existing as water and partly as suspended spray or moisture, is in part re-evaporated during expansion, thus providing that steam which is in evidence on the indicator diagram. If then the latent heat of steam at pressure P be represented by L, the quantity s of steam at pressure P that must be liquefied will be $\frac{U_{11}}{L} = \frac{160 \cdot 8}{904} = 0 \cdot 1779$ lb. $= s = 2 \cdot 85$ oz.

To do the work represented mechanically by 1 lb. of steam at 65 lbs. pressure isothermally expanded to 15 lbs. pressure will then actually require $1 \cdot 1779$ lbs. Part of the work so

* Mr. P. W. Williams, M. Inst. C.E., in one of the best papers ever published on steam engine economy ('Minutes Proc. Inst. Civ. Eng.,' vol. xciii.), assumes that the pressure varies as the reciprocal of the 7th power of the 6th root of space occupied, or that the ratio of mean to initial pressure $= \frac{Pm}{P} = \frac{7 - 6R^{\frac{1}{6}}}{R}$, but even this relation does not satisfy the conditions.

			Non-condensing Engines.					Condensing Engines.	
1	Total initial pressure $= P$	lbs.	65·	100·	150·	200·	300·	15·	65·
2	Terminal pressure $= Pt$	„	15·	15·	15·	15·	15·	3·75	3·75
3	Volume of 1 lb. of steam at pressure $P = V$	cub. ft.	6·49	4·37	2·988	2·282	1·565	25·86	6·49
4	„ „ „ „ after isothermal expansion to volume at pressure $Pt = V_1$	„ „	25·85	25·85	25·85	25·85	25·85	96·14	96·14
5	„ „ „ „ „ adiabatic expansion „ „ „ „	„ „	24·25	24·07	23·90	23·5	22·85	90·5	84·36
6	Ratio of expansion—isothermal $= R$	„ „	3·983	5·915	8·65	11·32	16·5	3·72	14·85
7	„ „ „ adiabatic $=$ „	„ „	3·75	5·5	8·0	10·3	14·6	3·5	13·0
8	Mean absolute pressure, isothermal expansion, Pm	lbs.	38·70	47·0	55·0	60·6	69·3	9·36	16·18
9	„ „ „ adiabatic expansion, „	„	28·77	46·7	53·55	59·4	67·5	9·33	16·11
10	Total heat at pressure $P = H$	.. ..	1172·76	1181·88	1191·22	1198·6	1209·46	1146·7	1172·76
11	„ „ „ „ $Pt = h$	.. ..	1146·7	1146·7	1146·7	1146·7	1146·7	1127·7	1127·7
12	Heat units given up $(H - h) = U_1$	.. ..	26·	35·	44·5	52·0	62·76	19·0	45·0
13	Latent heat of steam at pressure $P = L$	.. ..	904·	883·	861.	844·4	818·4	965·	904·
14	Total work represented by admission and expansion (isothermal) of 1 lb. of steam $= W$	ft. lbs.	144250·	174910·	204700·	225520·	357950·	129600·	224050·
15	„ „ „ „ „ „ „ (adiabatic) „ „ „	„ „	135400·	161850·	184300·	201000·	222050·	121300·	195800·
16	Heat units equivalent to total work W (isothermal expansion) $= U$	.. ..	186·8	214·0	265·2	292·0	334·15	167·8	290·0
17	„ „ „ „ „ „ (adiabatic expansion) $= Ua$	.. ..	175·4	209·65	238·75	260·5	287·62	157·2	253·6
18	Extra heat units required to perform the work $W_1 = (U - U_1) = U_{11}$	.. ..	160·8	179·0	220·7	240·0	271·39	148·85	245·0
19	Weight of steam corresponding to $U_{11} = \left(\frac{U_{11}}{L}\right) = s$	lbs.	0·1779	0·202	0·256	0·284	0·3315	0·154	0·271
20	„ „ „ total, corresponding to work $W = (1 + s) = S_1$	„	1·1779	1·202	1·256	1·284	1·3315	1·154	1·271
21	Work done against air, or back pressure (isothermal expansion) $= W_1$	ft. lbs.	55825·	55825·	55825·	55825·	55825·	41540·	41540·
22	„ „ „ „ „ „ (adiabatic expansion) $=$ „	„ „	52400·	51990·	51620·	56750	49350·	39096·	36450·
23	Available work $W - W_1$ (isothermal expansion) $= W_{11}$	„ „	88425·	119085·	148875·	169695·	202025·	88060·	182510·
24	„ „ „ „ (adiabatic expansion) $=$ „	„ „	83000·	109860·	132680·	150250·	172700·	82204·	159350·
25	Available extra work given off by U_4 (isothermal expansion) $= W_4$	„ „	..	30660·	39500·	20820·	32330·	..	94450·
26	„ „ „ „ „ „ (adiabatic expansion) $=$ „	„ „	..	26860·	22820·	17570·	22450·	..	77146·
27	„ „ „ per lb. of steam used (isothermal expansion) $= \left(\frac{W_4}{S_1}\right) = W_5$	„ „	..	25507·	31500·	16200·	24400·	..	74500·
28	„ „ „ per cent. $= \left(\frac{W_4}{W_{11}} \times 100\right) = W_{111}$ (isothermal expansion)	per cent.	..	25·75	26·5	12·3	16·0	..	52·0
29	„ „ „ „ „ „ „ „ (adiabatic expansion)	„ „	..	32·3	17·2	11·7	13·	..	48·4
30	Extra units of heat used in increasing $P = U_4$	.. ..	..	9·0	9·34	7·38	10·86	..	26·0
31	Total available work per lb. of steam actually used $= \left(\frac{W_{11}}{S_1}\right) = Ws$ (isothermal expansion)	ft. lbs.	75070·	99065·	118500·	132000·	151750·	76240·	143600·
32	Steam required per horse-power hour $= S$ (isothermal expansion)	lbs.	26·07	19·98	16·7	15·0	13·05	25·97	13·79
33	„ „ „ „ „ $= Sa$ (adiabatic expansion)	„	23·8	18·02	14·92	13·18	11·46	24·08	12·42
34	Saving in steam used per horse-power hour by each increase of pressure (isothermal expansion)	„	..	4·32	5·0	4·7	1·95	..	12·18
35	„ „ „ „ „ „ „ (adiabatic expansion)	„	..	5·78	3·10	1·74	1·62	..	11·66
36	„ „ „ „ „ compared with 65 lb. steam (isothermal expansion)	„	..	4·32	9·27	11·07	13·02		
37	„ „ „ „ „ „ „ „ (adiabatic expansion)	„	..	5·78	8·88	10·62	12·34		
38	„ „ „ „ „ „ „ „ (isothermal expansion)	per cent.	..	16·57	35·5	42·4	49·95	..	* 46·5
39	Extra units of heat used in generating steam at higher pressure, per cent. $= \left(\frac{U_4}{H - 200} \times 100\right)$	„ „	..	0·8	0·94	0·732	1·07	..	† 2·43
40	Available extra ft. lbs. per extra unit of heat used $= \frac{W_4}{U_4}$ (isothermal expansion)	ft. lbs.	..	3407·	4229·	2821·	2970·	..	3635·
41	Actual consumption of steam by Paxman's compound engine, Newcastle trials ($P = 165$)	lbs.	..	..	20·37				
42	„ „ „ Willans engine (S = simple, C = compound, T = triple)	„	(S) 33·0	(C) 22·9	(T) 19·5				
43	Efficiency of Paxman's Newcastle engine $= \left(\frac{\text{Line 32}}{\text{Line 41}} \times 100\right)$	per cent.	..	..	82·0				
44	„ Willans' engines $= \left(\frac{\text{Line 32}}{\text{Line 42}} \times 100\right)$	„ „	78·8	87·26	85·64				
45	Ratio of range of temperature used to absolute temperature $= \frac{T - t}{T} = E$	.. ..	0·262	0·290	0·315	0·333	0·362		
46	Increase in so-called efficiency E compared with E for 65 lb. steam, per cent.	.. ..	..	10·2	20·2	27·1	38·17		

* Compared with steam at 15 lbs. † $= \left(\frac{U_4}{H - 100} \times 100\right)$

To face page 231.

far referred to is used in overcoming a back pressure, in this case in displacing the atmosphere, and this quantity $= V_1 P t \times 144 = 55{,}825$ foot-lbs. Calling this W_1 then the available work $W_{11} = W - W_1 = 88{,}425$ foot-lbs.; and the available work performed per 1 lb. of steam $W s = \frac{W_{11}}{1 \cdot 1779} = 75{,}070$ foot-lbs. The horse-power hour being 1,980,000 foot-lbs., the quantity of steam at a pressure of 65 lbs. theoretically required is 26·07 lbs. per horse-power per hour. To this, however, must be added a further quantity to meet radiation and exhaust evaporation. The Table gives these figures for steam at the several pressures mentioned, and others are deduced from them, which help to afford an explanation of the very great increase in economy actually obtained by the use of high pressures. They also show what becomes of much of the steam actually used which has hitherto been deemed in excess of the theoretical requirements. Turning now to steam at 100 lbs. on the square inch, it will be seen from the Table that the difference between the heat units represented by the mechanical work of expansion, and the heat given up by the steam in falling from the initial to the exhaust pressure, is 179 units, corresponding to the latent heat of 0·202 lbs. of steam at the initial pressure. The quantity of steam required per horse-power thus becomes 19·98 lbs. As compared with 65-lb. steam there is thus a saving of 4·32 lbs. of steam per horse-power per hour, or of 16·57 per cent. The extra number of units of heat used to generate steam at 100 lbs. instead of at 65-lb. is only 9, and for this extra expenditure of heat 30,660 foot-lbs. of work are obtained, or 3407 foot-lbs. per extra unit. This is an extra available 25,507 foot-lbs. per lb. of steam used. The extra available work per cent. is $\frac{W_4}{W_{11}} = 25 \cdot 75$. From the 16·57 per cent. saving in steam used per horse-power per hour has to be deducted the extra expenditure of heat in generating 1 lb. of steam at 100 lbs. instead of at 65 lbs., the temperature of the feed for this comparison being taken as 200 degrees. This makes the extra expenditure of heat in the boiler 0·8 per cent., it would of course be less per cent. if the temperature of feed be taken at 32. The actual theoretical saving, deducting this 0·8 per cent., is then 15·77 per cent.

In the same way it will be seen from the Table that the saving in steam per horse-power per hour with 150 lbs. steam, as compared with 100 lbs. steam, is 5 lbs., or 9·27 lbs. as compared with 65 lbs. steam, or a saving, as compared with the latter, of

35·5 per cent. With steam at 200 lbs. the quantity of steam required per horse-power per hour is 15·0 lbs., or a saving as compared with 65-lb. steam, of 11·07 lbs. per horse-power per hour, or of 42·4 per cent. The saving by the use of 300 lbs. steam, as compared with 65 lbs., is 49·9 per cent. Deducting the extra heat required to generate the steam per lb., the actual saving by 200 lbs. steam is 41·6 per cent., and with 300 lbs. steam 48·88 per cent.

The gain per extra unit of heat expended in the boiler in raising steam at a higher instead of at a lower pressure is thus very large indeed, and it may be looked upon as increasing the potential energy of the whole of the heat expended in generating the steam to the lower pressure. As already mentioned in illustration, steam at 15 lbs. per square inch is incapable of doing work in a non-condensing engine, although 1146·7 units are expended in generating it, but by adding 26 units, or an additional 2·26 per cent., the steam is generated at 65 lbs. on the square inch, and is rendered capable of giving 75,070 lbs. per lb. of steam used.

Following the Table it will be seen that theoretically a great increase in efficiency should follow the use of high pressures at least to 300 lbs., and although the Table which accompanies this paper, only reaches that pressure, similar calculations show that there is considerable though a decreasing advantage theoretically attainable by pressures beyond that.

It will now be seen that the foregoing affords an explanation of the origin of the water found in all high pressure, steam engine cylinders. On the other hand the case may be taken of steam, admitted throughout the whole stroke, and therefore exhausted at full pressure. In this case the steam at the moment of exhaust will have the temperature of the initial steam, and the total heat carried away with the exhaust will be that of the weight of steam admitted to fill the cylinder. Heat equivalent to the whole of the work done, must have been provided altogether irrespective of the quantity required to fill the cylinder.

In such a case, if steam 65 lbs. total pressure be used to fill the cylinder in a non-condensing engine, the 1 lb. of the steam will perform $6 \cdot 49 \times 144 \times 65 = 60{,}740$ foot-lbs., equivalent to 78·6 units of heat, and to $\frac{78 \cdot 6}{904} = \cdot 087$ lbs. of steam nearly the available work $60{,}740 - (6 \cdot 49 \times 144 \times 15) = 60{,}740 - 14{,}080 = 46{,}660$, and this is performed by 1·087 lbs. of steam $= \frac{46660}{1 \cdot 087} = 42{,}925$ feet lbs. per lb. of steam and $\frac{1{,}980{,}000}{49225} = 40 \cdot 2$ lbs. per horse-power hour.

Thus with steam at 65 lbs. pressure, used without any expansion whatever, 1·087 lbs. of steam, or 1 lb. 1·4 oz. must be used for every lb. shown or accounted for by the indicator diagram. This is the minimum quantity, and to it must be added losses due to clearance not filled during compression, to radiation, and to conduction.

So far the author has only remarked upon the high efficiency possible with higher pressures than are commonly used, in all cases assuming a terminal pressure of 15 lbs. and a back pressure of the same amount. The higher back pressures in some engines will rapidly increase the quantity of steam condensed per available horse-power. It now remains to say a few words on the quantity of steam required when a condenser is used.

A calculation made on the same system as those which have been given, but assuming the maximum pressure P_1 to be 15 lbs., the terminal pressure $P\,t$ to be 3·75 lbs., and the back pressure to be 3 lbs., the total work W done by 1 lb. of such steam expanded isothermally is 129,600 foot-lbs., corresponding 167·8 units. The difference $U_1 = H - h = 19$ units, so that $U_{11} = 146 \cdot 8$ and the latent heat L at 15 lbs. being 965, the weight of steam to be supplied $\frac{U_1}{L} = \frac{146 \cdot 8}{965} = \cdot 154$ lbs. The work W_1 done against back pressure = 41,540, and the available work W_{11} = 88,060 foot-lbs. The foot-lbs. of work performed per lb. of steam is thus $\frac{W_{11}}{1 \cdot 154} = 76{,}420$ and the steam required per horse-power is 25·97 lbs. per hour, or 0·10 lb. less than the uncondensing engine requires of steam at 65 lbs. per square inch. Theoretically it will be seen that the foot-lbs. of work obtained per lb. of steam at 15 lbs. pressure used in a condensing engine is $76{,}240 - 75{,}070$ or 1170 foot-lbs. more than the work obtained with steam at 65 lbs. in a non-condensing engine.

Taking 65-lb. steam and using it in a condensing engine, the work performed reaches 143,600 foot-lbs. per lb. of steam used, or more than is obtained with a non-condensing engine using steam at 200 lbs. pressure, in both cases assuming isothermal expansion and a supply of heat by liquefied steam equivalent to the work done. The condensing engine using 65-lb. steam thus requires theoretically 13·79 of steam per horse-power per hour, but practically it does not give anything like so high a duty as is thus indicated; a fact which is probably largely due to the large range of temperature in the cylinder, the difference between the temperature of steam at 65. lbs. and at 3 lbs. being 156°, a much larger range of temperature than can be economically permitted in one cylinder. The pressure is small, but it would be obviously

of advantage to divide the range between two cylinders, and it is very probable that it would be found advisable with triple and quadruple stage expansion engines to expand down to at the most 15 lbs. in the third cylinder, so that the fourth cylinder received no steam at a pressure above that.

Now the validity of this method of arriving at the quantity of steam required per unit of work done, depends upon the validity of certain assumptions that were made, one of which was afterwards withdrawn. There are however some points to which it is necessary to recur.

It is not sufficient to say that we know that there is for every foot-lb. of work done a precisely equivalent dissipation or conversion or loss of heat. We want to know something precise as to where and in what way this loss, or rather conversion, takes place. On the answer to this depends a great deal as to the possibility of predetermining the quantity of steam that will be required per unit of work done in a steam engine cylinder, and what the amount of cylinder condensation. Does the conversion of heat into work result in simultaneous liquefaction in the space immediately behind the piston? Is the corresponding fall in volume, pressure, and temperature simply attended with further admission of steam until cut-off? Can it be assumed that the heat used in the cylinder up to cut-off is met by any exchange between cylinder and boiler as distinct from further supply by incoming steam? Up to the point of cut-off a steam engine cylinder may be looked upon as only an extension of the boiler steam space; but does this fact affect the mode of supply to the cylinder of the heat which is equivalent to the work done in the cylinder? Would not the liquefaction in any case take place in the cylinder or jacket or both? If so, it would only be when the cylinder is so placed that the liquefied steam drains or falls back into the boiler simultaneously with its liquefaction that the immediate connection between boiler and cylinder could have any effect. In this case, heat will be used in the boiler which will not make itself evident in steam in the engine. The engine will appear to work with less feed water, and the boiler to evaporate less for the fuel used than is actually the case.

Now in reply to these questions it may safely be said that in the real engine all the steam is received by it at the temperature due to the highest pressure shown by the indicator, and that the killing of steam molecules initially by admission to a cylinder cooled during a previous exhaust stroke, and subsequently by impact against a moving wall, or by the work of pushing a piston, is not met by a revivification before the port is shut of those slain molecules, but by a further slaying of the incoming army of steam molecules.

If this be so, then it would appear that the best possible steam engine, using steam supplied to it from a separate boiler, cannot use less steam per horse-power hour than that given by the formula on pp. 228–9. Further it will be seen that in almost all cases a slight loss must be added for radiation and conduction, and for clearance space not filled at initial pressure by compression.

A return must be made to the question of cylinder condensation. It is held by many theorists that there is theoretically no reason why high pressure steam should be more economically expanded throughout a given range in several cylinders than in one cylinder. The figures given in the Table show the work of a pound of steam, and the steam required per horse-power hour, irrespective of the system of expansion, except to this extent that it assumes no losses, except such as are due to the performance of work. This, in the author's opinion, presupposes the employment of multiple stage expansion, because there is theoretically ample reason for expecting much better results from expansion in several cylinders than in one.

A very great deal has been written by English and by Continental theorists on the great difference between the quantity of steam used by a steam-engine, and that accounted for by the indicator at cut-off, or that theoretically required by various methods of calculation. At present it is assigned to cylinder condensation in the early part of the stroke and re-evaporation at other parts including exhaust.

This action has been, until very recently, almost ignored in steam engine theories, but it has now been taken up vigorously and the thermodynamic theory of the steam engine as taught ten years ago is described as incomplete.

In England one set of theorists look upon the cylinder walls as a conducting medium of such efficacy that they give off enough heat during the exhaust stroke to account for the initial condensation, and that this condensation is an uncompensated loss. Others are of opinion that it is the wetness of the cylinder walls or water left in the cylinder after each stroke that absorbs the heat from the steam and increases the loss during exhaust. The exchange of heat that takes place between the periods of admission, expansion, and exhaust is, it is argued, conducted at a loss, and whether the iron walls or water on these walls or anywhere in the cylinder is the more active in causing the exchange and loss, is a matter of discussion. Dr. Zeuner in Germany, and Mr. Willans among others in England, are of opinion that initial condensation is due to water which remains in the cylinder after exhaust, and absorbs heat from the incoming steam. Mr. J. G. Mair, an engineer of great

experience in steam engine performance, dissents entirely from this view and appeals to the writings and experiments of Hirn, a well-known experimenter, and of those of the late Mr. Hallauer.

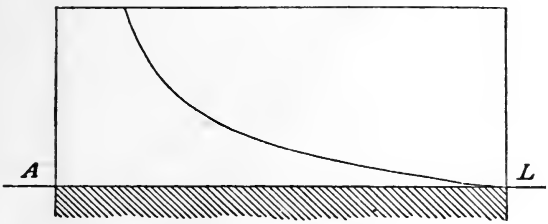
Mr. Willans' experiments appeared to show that cylinder surface had very little effect on the amount of initial condensation and hence Mr. Willans' opinion as to the effect of water retained in the cylinder. Profesor Unwin, on the other hand, satisfactorily shows that even if there were a water pocket in the cylinder, it is questionable whether an appreciable loss would be caused by its alternate heating and cooling, with attendant condensation and re-evaporation, and while he admits the reality of initial or general cylinder condensation, he expresses himself guardedly as to its real cause.

Mr. Willans' experiments, satisfactorily and it may be said conclusively, confirmed the opinion of all the builders of triple and quadruple stage expansion engines that the range of temperature in a cylinder is one of the most important factors in the determination of the quantity of feed water present in the cylinder at cut-off, but not as steam. They also showed that at least for non-condensing engines the time interval between the admissions, or the rotary speed, is an important factor.

There is, apart from a small quantity to be hereafter referred to, sufficient condensation and re-evaporation in the actual engine to show itself in the indicator diagram, by raising the pressure during expansion above the pressure it would otherwise have; so far as this re-evaporation takes place during expansion by heat given up from the cylinder walls condensation is balanced, but the evaporation which takes place during exhaust, is with large ranges of expansion in one cylinder probably greater, and the corresponding condensation is distinct loss. On this ground it may be argued that the multiple stage expansion engine should be more economical than the simple engine, because the exhaust stroke re-evaporation which takes place in all except the low pressure cylinder is utilised in each succeeding cylinder. This however, is only partly true. The re-evaporation during expansion may be taken as the same whether the steam at given pressure be expanded in one or in many cylinders, and the re-evaporation which takes place during exhaust may be taken to be the same, except for one reason, namely, that in the multiple expansion engine, the cylinder from which exhaust escapes is limited in its range of temperature; the temperatures on the opposite sides of its piston are not so widely different as in the simple engine. Re-evaporation cannot therefore be so much, and condensation is corre-

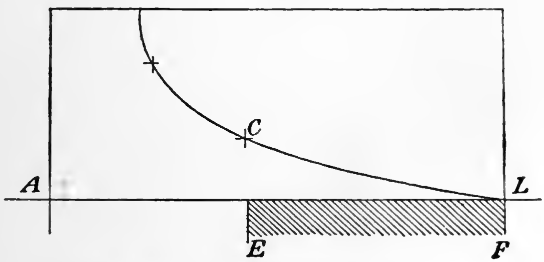
spondingly less also. In the multiple expansion engine, then, although the whole of the steam passes into the low pressure cylinder, and is exhausted from it at the same pressure as in the simple engine, the exhaust temperature only affects that part of the whole cylinder capacity in which a fraction of the expansion is conducted, while in the simple engine the exhaust temperature affects the whole cylinder capacity. This may be shown by the diagrams 1 and 2 which represent volumes and pressure in the two cases. In Fig. 1, supposed to represent the

FIG. 1.



simple engine, the line A L is the exhaust line, and the shaded portion below that represents the exhaust temperature existing contemporaneously during the whole admission and expansion history of the one volume of steam. Fig. 2 refers to a triple

FIG. 2.



expansion engine in which the range of pressure is assumed to be about the same in each cylinder. The third or low pressure cylinder receives the steam after it has fallen to the pressure at C, and the exhaust temperature only affects that part of the history of the volume of steam which is comprised in the short shaded portion.

Thus, although it is perfectly true that whether in one or in several cylinders, the steam must fall in temperature from that of the initial to that of the terminal pressure, only a small part of the iron of the multiple cylinders is exposed to the low

temperature. That is to say then, that instead of heating up a film of the whole cylinder capacity, for a given amount of power, from the temperature of the exhaust to the initial temperature of the steam, only a portion of the cylinder capacity is allowed to fall to the lowest temperature. An explanation of the difference can best be afforded by assuming a case.

Suppose two engines, one a triple expansion, and one a single cylinder engine, both engines of the same power, and both using steam at 200 lbs. pressure. Suppose on the one hand the triple cylinder non-condensing engine to have cylinders weighing respectively 100 lbs., 200 lbs., and 300 lbs., and on the other hand the single cylinder engine to have a cylinder weighing 400 lbs. : it may be supposed that in the first cylinder of the triple expansion engine, the expansion will reduce the pressure from 200 lbs. to 100 lbs.; in the second cylinder from 100 lbs. to 50 lbs., and in the third cylinder from 50 lbs. to 15 lbs. In the one cylinder engine the expansion must be such as to reduce the pressure from 200 lbs. to 15 lbs. Now if it be further assumed that a small fraction of each cylinder be affected to an equal extent per degree change in temperature, then the heat work to be performed in the two cases will be proportional to the following figures :—

	Weight of Cylinders.		Range of Temperature.			
Triple engine	100 lbs.	×	53·7	=	5370	35430
„ „	200 „	×	46·8	=	9360	
„ „	300 „	×	69·0	=	20700	
Single engine	400 „	×	169·5	=		67800
Difference in favour of triple engine						32370

That is to say, the single cylinder engine will lose nearly 94 per cent. more by the rise and fall in the temperature of the cylinder than will be lost by the triple engine.

It would be difficult to attempt a quantitative estimate of the loss incurred by this change in cylinder temperature or range of temperature of the contents of the cylinder, but it may be remarked in illustration that in the case of the assumed single cylinder engine, the temperatures on the opposite sides of its piston have a maximum difference of 169°, and that this is more than the difference between the temperature of the steam which passes into a condenser at a pressure of 4 lbs., and the mean temperature of the circulating water in the condenser. Even with a single cylinder engine, using only 100 lbs. steam, and exhausting at atmospheric pressure, the difference between the temperatures at the opposite sides of the piston, is greater

than the difference which obtains in a surface condenser, and if the mean steam temperature be taken, the range of temperature is more than half that between the two sides of the tubes in a condenser. The latter are, however, disposed so as to act most efficiently, while the steam cylinder and piston surfaces will only act as indifferent condenser surfaces. Inasmuch however, as about 2 square feet of surface per indicated horsepower may be made to suffice to condense all the steam coming from an engine, it may reasonably be inferred that the existence of very wide differences of temperature in very near parts of the same cylinder must have very wasteful effects, and that, correspondingly, the reduction of these differences will be beneficial.

Mr. W. Anderson, in his book on conversion of heat into work, mentions a case in which some good engines were found to consume very nearly as much steam in the jackets as would account for the work done. Professor Unwin, in the recent address already referred to, assumes this to demand from the jacket a power of evaporating water to the extent of the whole of the initial condensation which may be from 10 to 40 per cent., and thus require evaporative power approaching half the boiler heating surface. It must, however, be pointed out that this is not at all necessarily the case.

It is not supposed that a jacket in which that quantity of steam is condensed, has re-evaporated anything at all like 50 per cent. of the steam passed into the cylinder. It is in fact assumed that when a jacket acts effectively, there is but a small quantity of cylinder condensation, the water is not in the cylinder to be re-evaporated. It is supposed that the jacket has merely passed into the cylinder, the small number of units of heat represented by the work done on the piston. The proof of the accuracy of this assumption is given by Professor Unwin, in a foot note in which he mentions the fact that "In actual engines, a jacketed cylinder shows less re-evaporation, and has a lower expansion curve, than an unjacketed one." This clearly proves that some condensation has been transferred to the jacket, and that consequently there is correspondingly less re-evaporation possible in the cylinder.

From a consideration of that put forward in this paper it would appear that a steam jacket can have little if any value in triple or quadruple stage expansion engines and probably not in compound engines, and in any engine, its value is probably confined to the extent to which it limits condensation to the quantity which can be re-evaporated during expansion, leaving no evaporation to be effected during the exhaust stroke, whether of a single cylinder engine or the last cylinder of a

multiple stage expansion engine. It is possible that a jacket filled with steam, or some fluid at a temperature higher than that of the initial steam in the cylinder might more efficiently apply the heat used in it, but with a jacket supplied with steam at the temperature of that passed into the cylinder, re-evaporation is confined to a small part of the working stroke and is useless during exhaust.

In any good engine a large part of all that condensation usually called initial condensation, represents heat usefully supplied in perhaps as cheap a manner as any other that is practicable.

Upon the basis of the argument herein put forth, there is a small amount of re-evaporation during expansion, namely, that which could be effected by the heat contained in the liquefied steam, assumed to exist as water in the cylinder at cut-off, although most of it may exist during expansion as wet steam. It would of course be small, but may be approximately estimated. Taking steam at 200 lbs. pressure, the temperature T is 381·5 degrees. At atmospheric pressure the temperature T is 212 degrees, a difference growing as expansion proceeds from 0 to 169·5 degrees, representing 169·5 units per lb. of liquefied steam. This would be sufficient to evaporate $\frac{169 \cdot 5}{966} = 17 \cdot 54$ per cent. of the liquefied steam. With steam at 200 lbs. pressure, the quantity liquefied, as shown in the Table, is 0·284 lb. and the quantity re-evaporated would thus be $0 \cdot 284 \times 0 \cdot 175 = 0 \cdot 050$ lb. This is equal to 0·0385 lb. per lb. of steam used, and to $0 \cdot 0385 \times 15 \cdot 0 = 0 \cdot 576$ lb. per horse-power per hour. Assuming this to be completely evaporated during expansion, the quantity of steam actually required by the engine would be reduced to 14·43 lbs. per horse-power hour. Inasmuch, however, as some of it may be evaporated on the exhaust stroke, the estimate of 0·57 lbs. per horse-power hour is in excess of the quantity of re-evaporation acting in favour of the engine.

In conclusion, it must be remarked that the effect of different quantities of clearance has not been considered, but in well designed engines this with the usual amount of compression is sufficiently small to add very little to the actual consumption of steam. The losses due to radiation and conduction have also not been taken into account. When, however, these are added to the quantity of steam herein estimated as the minimum quantity required by a perfect practical engine, it will be found that the whole of the steam used by engines of different degrees of approach to the best possible practice, can be accounted for.

Discussion.

The President moved a vote of thanks to Mr. Beaumont for his paper, and called upon Mr. Pendred to open the discussion.

Mr. Vaughan Pendred said that while the paper contained a great deal with which he agreed, he wished to say at once, that there was a great deal in it from which he altogether dissented. Dealing with the practical side of the paper, he would turn first to the question of cylinder condensation, as depending upon the range of temperature. It was said that in multiple cylinder engines, the consumption of steam was reduced, because the condensation was reduced owing to the multiplication of cylinders. He dissented altogether from that view. The fact stated exerted an influence, but it was not the whole cause, or anything approaching to the whole cause, of the extra economy which was found in compound engines as compared with simple, and in triple engines as compared with compound. If the statement that the reduction in range of temperature materially affected the amount of steam that was condensed was true, it would follow as a matter of course that there would be very much less steam condensed in the triple expansion engine than in the compound engine. All the experience of which he was aware tended to show him that the condensation in the high pressure cylinder of the triple engine was enormous. In certain experiments made by Sir Frederick Bramwell with a triple expansion engine, it was found that sometimes as much as 45 per cent. of all the steam which came into the engine, was condensed. Other experiments had shown that as much as 30 or 32 per cent. might be condensed. During the last five years he had been acting as superintending engineer to the engines of the yacht Isa, a boat which was engined by Messrs. Douglas and Grant, of Kirkaldy. He believed that the engines of this vessel were the first triple engines that ever went to sea. The boat displaced about 250 tons, the high pressure engine had tandem cylinders and the low pressure engine had a single cylinder, and there were two cranks. The high pressure cylinder was 10 inches, the cylinder under it 17 inches, and the low pressure cylinder 28 inches in diameter. All the cylinders had a stroke of two feet. The engine worked with 120 lbs. pressure. The boiler was about 9 feet 8 inches in diameter, by 9 feet 8 inches long, and it had a large steam drum on the top, which was connected with the boiler by two necks. The steam pipe coupling the high pressure cylinder with the boiler was very short, being he should think not more than 4 feet. At the back of the stop valve separate pipes took steam to the jackets. The high

pressure cylinder and the intermediate cylinder both had jackets, but the low pressure cylinder was unjacketed. The safety valves were loaded at 120 lbs., and at 119 lbs. in the boiler—that is to say, when the safety valve was just on the point of blowing off,—and when the boat had got about 10 tons of coal on board the engines made 107 revolutions, and they indicated as nearly as possible 200 horse-power. The boiler had two furnaces, and 162 tubes of $2\frac{3}{4}$ inches in diameter, and about 7 feet long. The furnaces were 5 feet long and 2 feet 8 inches in diameter. It would be seen that these were very large proportions of boiler for supplying a 10-inch cylinder.

The engine carried steam $\frac{3}{4}$ of the stroke in the high pressure cylinder, about $\frac{5}{8}$ of the stroke in the intermediate, and nearly $\frac{3}{4}$ of the stroke in the low pressure cylinder. Originally she cut-off at an earlier point in the high pressure cylinder, but inasmuch as the boiler always made an abundance of steam, and the then owner wanted more speed, he had some of the lap cut off the valve. Taking the coal bills, the miles run, the average of power, the speed, and so on, the vessel ran as regularly as possible with $3\frac{1}{2}$ tons of Welsh coal for 24 hours for 200 horse-power. That was not the result of experiments, but was derived simply from the actual coal bills paid. They were the best test which could be had. He had indicated that engine repeatedly, and had made such experiments as could be roughly carried out at sea. Under all possible circumstances he had found that the high pressure cylinder was drowned with water. It was impossible to get a dry diagram from it. The intermediate cylinder was much better. In the low pressure cylinder which communicated with the condenser, the steam was absolutely dry, and could not be seen until it got a short distance from the indicator cock. When this happened the cylinder was practically so cold that one's hands could be tapped upon the top of it without being burned. The jacket had a glass gauge fitted at the side, and a very considerable quantity of water condensed in it was drawn off into the condenser. At one time this water was allowed to flow into the bilges, but a change had been made in this respect, because the loss of water was practically so considerable that there was a risk of getting the boiler salt. He had tried the engine with the jacket carefully blown through and left perfectly dry. Also he had tried the engine with the jacket full of water, and again he had tried it with the steam cut off altogether, but he never could find that there was the slightest difference in the amount of steam which was condensed in the high pressure cylinder. He was very much surprised at first by these results, and wrote to two or three superintending

engineers asking them what their experience was, the replies being to the effect that in all cases the high pressure cylinders of triple engines worked wet. Mr. Mudd, of the Central Engineering Works, had said to him "I always find that the high pressure cylinder is wet. I cannot account for it in any way except that I believe that all marine boilers send a very large quantity of water into the cylinder, and what you consider to be condensed steam is really priming." He (Mr. Pendred) could understand that under certain circumstances there would be a large quantity of priming, but he was at a loss to see how there could be priming at all in the case of the Isa. She worked with perfectly clean water, and there was a large separator on the top. The steam capacity of the boiler was enormous as compared with the size of the cylinder, and as far as he could see there had been no draught whatever of water from the boiler at any time into the cylinder. He was not ashamed to say that the reason why the water appeared in the cylinder was a complete puzzle to him. He believed that he was right in saying that no one who had dealt with the triple expansion engine had been able to show that there was less condensation in the high pressure cylinder than there would be if the engine was not triple. The reason why any compound engine was more economical than other engines appeared to him to be due to the re-evaporation which took place. Mr. Beaumont incidentally alluded to that point without adopting it. The whole of the steam which had to come into the engine as water was evaporated, because as he had said the low pressure cylinder delivered absolutely dry steam. He found that triple engines as a rule worked extremely dry steam in their low pressure cylinders.

Mr. J. Macfarlane Gray said that evidently the author had given a great deal of thought to the subject treated in the paper. He had not been able clearly to follow the very condensed explanations which had been read, and perhaps, because they had been so condensed; the impression he had received was that some of the thoughts expressed were yet, even in the author's mind, immature. For the purpose of discussion he thought the author deserved the thanks of the meeting for bringing the paper before them.

In regard to the new formula propounded in the paper:—

$$S_1 = 1 + \frac{\frac{W}{J} - (H - h)}{L}$$

it seemed to him that if S_1 is the weight of steam, including

condensation, required to perform the work W between two given temperatures, the formula admitted of a simplification which would allow us to see more readily what it really said. When written out for $S_1 = 1$, we get—

$$1 = 1 + \frac{\frac{W}{J} - (H - h)}{L}$$

$$\therefore\ L = L + \frac{W}{J} - (H - h)$$

$$\therefore\ \frac{W}{J} = H - h.$$

That is, the work done by one pound gross is the mechanical equivalent of the table difference of the total heats of one pound of saturated steam at the initial and final temperatures. He thought the author meant that the steam is to expand as saturated steam, and S_1 is the gross weight of steam, allowing for a part to condense to supply the heat to maintain the expanding steam at saturation. If that was his meaning then the formula was incorrect, for it gives only the weight of what will be steam at the final temperature, and it allows nothing whatever for the weight of the steam which supplies heat by condensing.

He did not agree with the author's remarks about Carnot's theorem. He thought that theorem was perfectly correct and most simple and readily applicable to any steam engine. If applied according to the instructions of Clausius or Rankine, the conclusions arrived at would be quite as reliable as, for example, the usual formulæ for the strength of girders of different forms of section.

Generally Carnot's theorem has been erroneously applied. Clausius and Rankine both directed that the amount of heat converted into work was to be arrived at by dividing the area on the thermodynamic field into elementary adjacent bands, each bounded by the limiting temperatures of heat acceptance and heat rejection, and then adding these heat areas. On this plan the higher temperature for the feed-heating is continuously increasing, and the sum of these areas then is therefore a triangle.

In applying the common expression $\frac{T - T_1}{T}$ the utilised heat area is taken as one rectangle, and a fictitiously high efficiency is thereby arrived at,—an efficiency exceeding what could be obtained from a perfect engine. It was to avoid this error

that he made the formula which has been referred to under his name in the paper. In that formula there was nothing new, it was identically Carnot's theorem as given by Clausius and by Rankine, only he had substituted for a logarithm an equivalent in common arithmetic. This substitution gives a numerical result slightly in excess of strict accuracy, in the proportion, say, of 772 to 770 in practice, and this excess has been rectified by using 770 instead of 772 for Joule's equivalent.

Clausius, and Rankine also, in their investigations in thermodynamics regarded the heat received by the working fluid as an area forming what might be called the thermodynamic field and the boundary outline of that field is always the same for the same substance. The line for water heating is an ascending curve, the line for the state of saturated steam is a descending curve, the breadth of the field from a straight datum line is the absolute temperature of the fluid in its different stages of heating, evaporating, expanding, and exhausting. All below the final area is lost area or lost heat. The limiting temperatures define the useful part of the field and the feed heating end of that portion is necessarily a triangle, and this fact is erroneously ignored when the common expression $\frac{T - T_1}{T}$ is applied as the standard of efficiency of the perfect engine.

On the thermodynamic field, adiabatic expansion is represented by a vertical straight line which divides any temperature line in the field, in that proportion in which the expanding fluid at that temperature consists of steam and of liquid. When Carnot's theorem is set out for any engine, on such a field, the result is always in accordance with the actual facts of the engine.

Mr. ARTHUR RIGG said that the subject was a deeply interesting one, and in its consideration Mr. Beaumont had in one part of his paper spoken about clearances in the cylinder. He (Mr. Rigg) could not help thinking that what might be called the evil reputation for extravagance, which some high speed engines had once acquired was due, possibly, to the necessity for having large clearances, a provision which some German authors pointed out as essential in locomotives.

When steam first entered into the cylinder of an engine provided with a large clearance space, its first work was to fill up these spaces, with the assistance of whatever might be gained by compression of the exhaust, until the cylinder may be considered in exactly the same position as if there was no clearance space at all. The steam had to compress up to the full pressure shown by an indicator before the piston begins to move, and so become a sort of buttress to serve for forcing the piston forward

If they took the most economical engines; the Corliss for instance, which was an enormous stride in advance of its predecessors, they would find that for all practical purposes the clearance space had vanished altogether, or at least bore a very small proportion to the cylinder capacity. The slide valve was in this type taken across the cylinder, and the enormously long stroke minimised the proportion of the clearances. He thought that they were all indebted to Mr. Willans' engine for having exploded the popular superstition that because an engine was a quick-running engine, that it must be uneconomical, and engineers had now come to the conclusion that nothing was better for the increase of economy than high speed. The more quickly an engine was run, the less time was there for condensation, and they all knew what an advantage that was. The result of the experiments with Mr. Willans' engine, was to prove that high speed engines, as they were made in that particular example, were exceedingly economical; in fact, nothing could very well beat them. He had found high speed engines very much the opposite in some cases, when they were running empty so that they had to be loaded before the best economy could be attained. So far as he understood Mr. Willans' engine, it had a central valve and exceedingly small areas of passages, and by this arrangement, there were very small clearances in proportion to the area, which was swept over by the piston. He (Mr. Rigg) thought that therein lay one of the reasons why, with comparatively low powers, Mr. Willans had secured great economy. In high speed engines there is bound to be a considerable compression to bring the piston up to rest, or the engine would knock itself to pieces; but where there was a gradual resistance against the piston, it was quietly brought to rest.

Mr. E. Perrett said that he had run an ordinary three cylinder engine, with highly superheated steam, and it only used ten pounds of water per horse-power. Of course there were many difficulties attached to the use of the superheated steam.

Mr. G. R. Bodmer, said that he had been very much interested in Mr. Beaumont's valuable paper, but there were one or two points on which he differed from him. As had been pointed out, any apparent differences between theory and practice, were due chiefly to a misapplication of theory. Of course Carnot's well-known formula only applied to an ideal engine, which had a certain peculiar cycle. It was perfectly true that the work done by two different engines was proportionate to the difference of temperatures, provided that both were performing the same cycle. If they were not performing the same kind of cycle, it would be of no use whatever to take as a basis of

comparison the range of temperature. Taking the cases of a single cylinder engine and of a triple expansion engine, the probability was that the one would be working with quite a different kind of cycle to the other. Comparison of the work done on the basis of the difference of temperature was useless. unless the different kinds of constants appropriate to the cycles of the two engines were taken into account. Another point requiring some remark was, that most engineers assumed adiabatic expansion for the so-called thoretical diagram, and they always used Rankine's formula for defining it. That was only an approximate formula; many engineers did not seem to be at all aware that the adiabatic expansion curve could be calculated on perfectly correct theoretical lines, and that the amount of water present should be taken into account. Professor Cotterill, amongst others, had dealt with this subject in his work. The point was pretty well understood amongst scientific men, but was generally ignored by engineers. It was a very important point, because the amount of condensation taking place during expansion in a non-conducting cylinder depended upon the proportion of water present at the moment of cut-off. According to that proportion of water would be the form of the adiabatic curve. There was any number of adiabatic curves; Rankine's formula only expressed the adiabatic curve for *initially dry* steam, but if, as in most cylinders, the steam was mixed with a large quantity of water, the adiabatic expansion curve would not be represented by Rankine's formula at all, but would differ considerably from the form resulting from the latter. The true formula was somewhat complicated, but was by no means difficult to apply. He had been much interested by Mr. Pendred's remarks about the triple expansion engine with which that gentleman had experimented; he (Mr. Bodmer) was not prepared to explain the reason of the large amount of initial condensation, taking place in the high pressure cylinder, but the fact that the steam subsequently became dry was quite in accordance with theory. In fact, what he had just said about the adiabatic expansion curve bore upon the subject. If there was over 50 per cent. of water present at the moment of cut-off, then, according to theory, there would be re-evaporation if expansion occurred adiabatically; in reality there was more re-evaporation than corresponded to adiabatic expansion. He thought that the large amount of water present at the moment of cut-off in the triple expansion engine, spoken of by Mr. Pendred, accounted for the subsequent re-evaporation. It did not follow, that because there was a large amount of initial condensation in this triple expansion engine, there would not be more in a simple engine using the same high pressure, but in a triple

expansion engine, a very much higher pressure was adopted than would ever be thought of in a simple cylinder engine. The comparison of these two classes of engines would be of value only when they both used *the same initial pressure and the same expansion ratio.* It was highly probable, that the triple expansion engine spoken of by Mr. Pendred, condensed much less steam initially than a single cylinder engine, using the same pressure and expansion ratio, would condense.

Mr. Schönheyder said that he wished that they had half a dozen Macfarlane Grays at the meeting to thrash the subject out. They were very much indebted to Mr. Gray for putting his remarks so plainly in the shape of a diagram. How perfectly helpless engineers were in dealing with steam, and how very little work they could really get out of the whole heat which was stored in it, was shown very clearly by the small proportion which could be utilised out of the piece of cloth which Mr. Gray had used as an illustration. In speaking of the efficiency of an engine it was a common thing to say that such and such an engine gave an efficiency of say 95 per cent. That would be right if they said that every engine received a certain amount of heat and threw away a certain amount of heat, and out of the difference gave say 95 per cent. efficiency, but it was not at all the intention of the engineer that so much heat should be wasted. They designed engines in order to get as much work as possible out of the heat which they imparted to the steam. He looked upon the engine as a very bad child whom they might send to school and flog and try to perfect as much as they liked without ever getting much advantage out of it. They would never obtain a high economy out of a steam engine. Instead of saying that they got an efficiency of say 80 or 90 per cent. out of an engine, if they were to speak the real truth they would say that out of the very best kind of engines they only got some 10 or 12 per cent. efficiency. If they constantly spoke in that manner they would always be reminded of what an inefficient machine a steam engine was for the conversion of heat into work.

Mr. Charles Cowper said that Carnot's law was of course a law applicable to all *heat* engines. He understood that Mr. Beaumont wished to base his comparison on some footing more peculiarly suitable for *steam* engines in particular. He did not quite understand from what calculation Mr. Beaumont obtained the quantity represented by the symbol "S" on the board. He wished to know whether Mr. Beaumont based these figures upon the quantity of steam accounted for by the indicator; he hardly thought that it could be so, because a

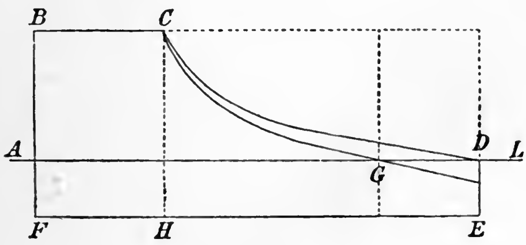
steam engine worked, not with steam alone, but with a mixture of steam and water in varying proportions. In a very economical compound rotary pumping engine, with steam jacketed cylinders, the total quantity of water passing through the engine, not including the jacket steam, measured carefully in a twenty-four hours' trial, was 13·4 lbs. per I.H.P. per hour. Something like 24 per cent. of the water was not accounted for by the indicator at the time of cut-off in the high-pressure cylinder; that is, 24 per cent. of the weight of the mixture was in the form of water, and only 74 per cent. in the form of steam. The quantity of water present was gradually diminishing during the working period in the high and low pressure cylinders. The quantity at the end of the low pressure stroke was only about 2 per cent. Now this 24 per cent. of water found in the cylinder at the cut-off (owing to the initial condensation, and probably also to some "priming" from the boiler), was re-evaporated by the heat of the walls, assisted no doubt by the jackets. It was obvious, therefore, that the curve drawn by the indicator was not that due to the expansion of a definite weight of isolated steam, but that due to the expansion of a constantly varying amount of steam. A former speaker had raised the vexed question of the adiabatic and the isothermal curves. He (Mr. Cowper) did not think it was really worth while to split hairs as to the exact theoretical curve, because they found that in reality they never obtained the theoretical curve, on account of this re-evaporation. The best engines, in his experience, gave a curve decidedly above the isothermal line, the "index" of the curve being not Rankine's $\frac{17}{16}$ (or $\frac{10}{9}$ as named by a previous speaker) but a number on the other side of unity. The best engines gave about 0·9 or 0·85 as the "index" of the curve.

Mr. Beaumont, in reply, said that he had brought the paper forward simply for the purpose of discussion. There were many points in connection with the steam engine in which there was a very great difference between what they would anticipate and what they actually found in the very best engine that could be made, and that being so he considered that any views of the subject which seemed to be rational were better brought forward to be discussed than to wait for years until it had been completely developed into a more or less perfect theory. Mr. Bodmer had, he thought, replied to the greater part of Mr. Pendred's remarks by saying that there was nothing to show that there would be necessarily less condensation in a single cylinder engine than in a triple expansion engine using the same pressure and the same range of expansion. The fact mentioned by Mr. Pendred that

there was a large quantity of water in the high pressure cylinder in a triple expansion engine was not in the least degree in opposition to what was stated in the paper. This was shown by reference to the table at the end of the paper. He did not know how Mr. Pendred could have understood him (Mr. Beaumont) to refer to the re-evaporation without adopting the explanation in question, for he had put up a diagram purposely to indicate that he considered that the re-evaporation was all useful in the triple stage engine as represented, with the exception of that which took place on the exhaust stroke of the low pressure cylinder. Mr. Macfarlane Gray had said that when he (Mr. Beaumont) took a pound of steam and assumed that he had a pound of steam at the end of the stroke he was wrong. If he had really done so, of course he would have been wrong. He assumed that he had a pound of steam to begin with admitted to the cylinder, and he expanded it to the pressure belonging to a given volume of steam, that volume giving him the range that he adopted in order to find the work done in that particular cylinder. Under these circumstances he should have of course to allow for a quantity of condensation, that is to say a quantity which would by condensation supply heat equivalent to the work done. He left that out of the question until he arrived at the number of foot-pounds of work represented by the quantity of steam in the cylinder as shown by an indicator diagram, and then he found how much steam should have been provided so as to supply the heat necessary in order that steam should have existed under the assumption that he made. Instead of saying in the first instance "How much work will a pound of steam do," he said "How much heat must I supply to a pound of steam in order that it may remain a pound of steam at the end of the operation." With respect to what had been said by Mr. Macfarlane Gray as to Carnot's theory, he (Mr. Beaumont) hoped that he made it understood that he held that while it was useful as a sort of ulterior reference, it was absolutely impossible to use it at all usefully or to any purpose in comparing engines working under different conditions and through different ranges of expansion or temperature. Mr. Perrett seemed to have misunderstood the purport of the paper, but it would be perhaps of some use if he would tell the Society what was the result of the use of superheated steam, for if superheated steam could be used in practice, it would overcome the loss which resulted from the necessity of condensing a certain amount of steam in the cylinder in order that that which was shown by the indicator might remain steam until it had done its work.

Mr. Cowper had asked what was the object at which he (Mr. Beaumont) wished to arrive; when a man spoke of an engine being efficient to a certain percentage there was at present no certainty as to what he meant. What he (Mr. Beaumont) wanted to arrive at was some comparison which would enable engineers to say what was the least quantity of steam that an engine doing a given amount of work could use, and compare that with the quantity that it actually did use. He wished to separate from the engine everything which had to do with the boiler. One word as to the adiabatic expansion. Mr. Bodmer in particular referred to that question. Just for a certain part of the paper, he (Mr. Beaumont) had assumed adiabatic expansion. Of course they might take in all the indices for the different assumptions. Mr. Willan in his particular case assumed that the variation in the pressure during expansion was in the proportion of $PV^{\frac{7}{6}}$. That was simply for arriving at a mean pressure for the sake of settling his range of expansion. He (Mr. Beaumont) had used $PV^{\frac{10}{9}}$ simply to arrive at the mean pressure during the stroke in the example given at page 225. Mr. Cowper had said that whether the adiabatic or the isothermal curve were taken made very little difference. He (Mr. Beaumont) thought that there was some mistake about that. For instance let them take the following diagram.

FIG. 3.



It was perfectly true that the distance between the two curves or ordinates of pressure was very little, but the actual importance of the difference was better seen by noting that the horizontal ordinates of volume were much less for any given pressure with adiabatic expansion. For instance assuming the volume F B C H to expand isothermally to the atmospheric pressure A L, the volume would at that pressure be represented by the horizontal ordinate A D. Under adibatic expansion the volume at the same pressure would be represented by

the horizontal ordinate A G. As to the very economical engine that had been mentioned as Mair's engine, and which was made by Messrs. James Simpson & Co., and used at the West Middlesex Waterworks, the efficiency of that engine, which was he believed unique, appeared to be about 0·89 according to his way of looking at the matter. In reply to Mr. Macfarlane Gray, he said that S_1 in the formula represented the weight of steam actually used for every 1 lb. of steam shown by the indicator diagram.

Obituary.

Mr. William Eassie, the well-known sanitary engineer, died on August 16th, at his residence in King Henry's Road. He was born at Lochee, Forfar, in 1832, and his early life was chiefly devoted to engineering pursuits, when he became a favourite assistant to the late I. K. Brunel, and, along with the late Dr. Parkes, F.R.S., he superintended the sanitary arrangements of Renkioi Hospital during the Crimean War. At the conclusion of hostilities he took a band of navvies and made the first excavations on the site of old Troy. In 1872 he published 'Healthy Houses,' and subsequently a work on 'Sanitary Arrangements for Dwellings.' In 1874 he published his work on 'Cremation of the Dead.' He was a prominent member of the council of the Sanitary Institute of Great Britain and of its examination board until his decease, a fellow of the Society of Arts, and an honorary member or fellow of various learned societies on the Continent, especially of those dealing with matters of hygiene.

Mr. Andrew Kerr. Since the issue of our last volume, information of the death of this member (foreign) has been received. He served his apprenticeship in the years 1848–52 to Messrs. Hawthorn & Co., Locomotive Engineers, Leith. He was elected a member of the Society in 1878, and at the time of his death held the post of town surveyor at Warnambool, and engineer to the Shire Council of Mortlake, Victoria, Australia.

SOCIETY OF ENGINEERS.

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1861 to 1888.

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